The University of Chicago

GEOLOGY OF THE SERPENTINE BELT COLERAINE SHEET THETFORD-BLACK LAKE MINING DISTRICT QUEBEC

A DISSERTATION

SUBMITTED TO THE FACULTY OF THE OGDEN GRADUATE SCHOOL
OF SCIENCE IN CANDIDACY FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

BY

JOHN KNOX KNOX

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GEOLOGY OF THE SERPENTINE BELT
COLERAINE SHEET
THETFORD-BLACK LAKE MINING DISTRICT
QUEBEC

By JOHN KNOX KNOX

CHAPTER I.

INTRODUCTION.

GENERAL STATEMENT.

The serpentine belt in the Eastern Townships of the Province of Quebec was chosen for special geological study more than ten years ago, primarily because it contains the largest and richest deposits of chrysotile asbestos yet discovered in the world. Production began there in 1880 and has steadily increased both in value and in volume up to the present day. The Geological Survey of Canada, therefore, undertook the present investigation in order to come to some conclusions as to the origin of the chrysotile deposits, so that prospecting of the large areas of serpentine which are, as yet, unproductive, might be intelligently undertaken.

The deposits of chromite found associated with the asbestos-bearing rocks are also of interest and of present economic importance owing to the war-time demand for this ore.

This work has not been completed, but as all the known igneous types have been examined and as future work will consist largely in mapping the distribution of the different phases in adjoining territory and in an intensive study of conditions in the operating mines, the petrography of the serpentine series can be described conveniently at the present time.

FIELD WORK AND ACKNOWLEDGEMENTS.

The field work upon which this report is based was carried on during the summers of 1915 and 1916. In all about seven months were spent in camp. Several short excursions were made into neighboring districts in search of evidence bearing on one or other of the problems, particularly that of the correlation of the sedimentary formations. During the first season attention was directed chiefly to the sedimentary rocks; during the second summer the igneous complex was made the subject of particular study.

The writer wishes to record his indebtedness for much helpful criticism and suggestion to Mr. R. Harvie of the Canadian Geological Survey under whose direction the work was first undertaken, and to Mr. A. B. Gilbert who as assistant rendered very ready, efficient, and intelligent service in the field.

More than 200 specimens were collected and the petrology of this report is based on the microscopic study of slightly more than 200 thin sections. This work was carried on in the petrological laboratory of the University of Chicago during the winters of 1916 and 1917 under the direction of Professor Johannsen of the geological staff, to whom the writer is much indebted for frequent help and criticism.

In the preparation of the accompanying geologic map outcrops were located wherever possible by the use of the topographic base. All important contacts were run by plane-table survey using fore and back sights, or, where this was impracticable on account of the undergrowth, by compass and tape.

LOCATION AND AREA.

The Thetford-Black Lake map-area lies in the Eastern Townships of the Province of Quebec, about 75 miles slightly west of south of Quebec City on St. Lawrence River, and 75 miles north of the international boundary (see key-map on geologic map at end of report).

The Thetford-Black Lake topographic map embraces an area of about 225 square miles. It was prepared in 1913 and 1914 by D. A. Nichols of the topographic division and will be published on a scale of 4,000 feet to one inch with a contour interval of 20 feet.

At the close of the field season of 1916 the geologic mapping of two-thirds of this area had been carried out in a preliminary fashion with regard especially to the sedimentary formations, and the southwest quadrant had been virtually completed in all details. It is with this latter portion, including an area of about 65 square miles and to which the name Coleraine sheet has been given, that this report will deal.

MEANS OF COMMUNICATION.

The Quebec Central Railway which runs from Sherbrooke to Quebec City, passes through the area from north to south and affords excellent transportation facilities.

One of the two important highways running through eastern Quebec from the United States to the St. Lawrence parallels the railway line, more or less closely, for more than 100 miles. To the south the road is of fairly good macadam or gravel construction, but for the 12 miles from Disraeli to Black Lake it is of clay, sand, or at best thinly gravelled, and usually is in very bad condition. This highway possesses many scenic attractions and could be made very popular with tourists from the neighbouring states if it were put in good shape for automobile traffic. Bad as the road now is the traffic is considerable.

Abundant and readily accessible supplies of excellent road metal lie close at hand throughout this stretch. Short stretches of splendid roadway in Black Lake village and between Black Lake and Thetford afford evidence as to the sort of highway which can be built of the local materials.

The less important roads are of clay or gravel and quite good considering the sparsely settled nature of the country.

PREVIOUS WORK.

The first important geological work in this general region was done by Sir William Logan and T. Sterry Hunt. Their views on the nature and origin of the igneous rocks are given in the Report of Progress for 1863.

In 1882 F. D. Adams showed by microscopic study that the serpentines are not altered sediments as the two earlier investigators had thought.

In the annual reports of the Canadian Geological Survey, new series, for the years 1886, 1887, and 1888, R. W. Ellis describes the asbestos-producing area in detail as part of his work on the geology of the Eastern Townships.

In 1905 the Mines Branch of the Department of Mines published a report on the origin, mining, and milling of asbestos and an enlarged and rewritten edition of the same report in 1910. Both of these reports are by F. Cirkel.

Between 1907 and 1910 J. A. Dresser examined the whole area of the serpentine belt. His investigation, however, was of a preliminary character and extended over a much larger area than that described in this report. The results of his work are given in Geol. Survey Can., Memoir 22.

A short readable summary outlining the state of knowledge in 1913 may be found in Guide Book No. 2 prepared for the use of the International Geological Congress which met in Toronto in August of that year.

OBJECT OF THE PRESENT INVESTIGATION.

The purpose of this detailed investigation is to solve, if possible, the relations of the different members of the serpentine series to one another and to the sediments which they intrude; to determine the structural form of the igneous bodies; to provide a map which will accurately show the distribution of those rocks in which commercially valuable deposits of asbestos are likely to be found; and by microscopic study of the altered and unaltered differentiates of the basic magma, to throw more light on the origin of the chromite and the asbestos.

In this connection it is very desirable that all possible assistance be given the mining industry. In 1914 the mines of the region produced about 80% of the world's supply of asbestos. In 1915, after eight years of non-production, nearly 10,000 tons of chromite were exported to the United States to meet the demands arising from war conditions.

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[1] Geol. Sur. Can., Memoir 22, pp. 4-5, 1913.

CHAPTER II.

SUMMARY.

The only consolidated sediments present in this area are quartzites and slates. These rocks range in age from pre-Cambrian to Ordovician. Silurian and Devonian beds probably were present at one time, but they have been removed entirely by erosion.

Cambrian quartzite rests unconformably on pre-Cambrian quartzite, and a second unconformity probably exists between the Cambrian and the Ordovician, as shown by the pebbly basal member of the Farnham slates. The total absence of fossils makes lithology and stratigraphic position the sole basis of a correlation which is thus left much less definite than could be desired.

The igneous rocks were intruded along the southeast flank of the Sutton anticline in post-Ordovician times. The igneous rock within the area belongs to the thin, sheet-like edge of a rather thin laccolith. Eastward from Belmina Ridge and Caribou Mountain the intrusive horizon was between the L'Islet formation and the overlying slates, but if the igneous body extended westward from these hills, as it most probably did, it was at a different stratigraphic horizon.

The igneous rocks, when intruded, ranged from ultra-basic dunites to acidic granites and aplites. Differentiation of the main types took place after the intrusion. The granites and aplites were differentiated in the magma basin and injected into the other rocks as the last phase of igneous activity.

The intrusion did not all take place at one time but was progressive. Small masses burst up through rocks previously intruded and already partly cooled. The later intrusions were more and more acidic in character, ranging from pyroxenite to aplite and pegmatite.

Since intrusion the rocks have been folded and greatly altered, and the igneous series has been removed entirely from the higher anticlines. In the more basic members chromite and asbestos are found. Up to the present no important deposit of asbestos has been found south of Black Lake. Small amounts of chromite are mined on Caribou Mountain, but the mining operations within the area have not, up to the present, been extensive or profitable. In the writer's opinion, prospects of commercial deposits of either of these minerals being found within the limits of the map-area are not attractive.

CHAPTER III.

GENERAL CHARACTER OF THE DISTRICT.

TOPOGRAPHY.

GENERAL.

That part of the Province of Quebec lying to the south of River St. Lawrence may be divided topographically into two portions along a curving line running from the north end of Lake Champlain to the city of Quebec. To the west of this line is a plain underlain by nearly horizontal strata of Paleozoic age. To the east, and marked off from the plain by the great St. Lawrence-Champlain fault, are the Appalachian Highlands. These highlands are the northerly continuation of the Appalachian System of the United States and extend for 300 miles in a northeasterly direction from northern Vermont into Gaspe Peninsula.

In the Eastern Townships the highlands consist of three main parallel anticlinal ranges of low hills known as the Sutton, Stoke, and Megantic ranges. Of these, the Megantic Range lies farthest to the east and forms part of the boundary between Quebec and the State of Maine.

In the southern part of the Province, near the international boundary, the three ranges are each only a few miles across and are rather sharply defined. Farther north, in the Thetford region, the most westerly or Sutton Range widens out until it is 15 miles in width, with an altitude in many places along the broad-topped ridges of from 1,500 to 2,100 feet above sea level. In about the same latitude the central, or Stoke Mountain Range, decreases markedly in height, and to the north of Lake St. Francis it loses its identity as a prominent topographic feature.

The igneous rocks of the serpentine series have been intruded into the sedimentary rocks along the eastern flank of the Sutton Range throughout the whole of its length from Chaudiere River to beyond the international boundary, far into the State of Vermont. In many places these igneous rocks form abrupt, prominent hills or long steep-sided ridges which rise to 1,800 and 2,000 feet above sea level and in one place reach an elevation of 3,000 feet.

Practically the whole area of the Eastern Townships is drained into the St. Lawrence by a number of large rivers which, with scarcely an exception, cut across one or more of the Appalachian ranges in a direction almost at right angles to the general trend of the hills. Where they cross the hills, and in the lower part of their courses, the rivers are without falls or rapids and clearly are antecedent streams. In the upper reaches which in some cases make an angle of as much as ninety degrees with the direction of the lower part of the course, the rivers are younger. Here they have steeper-sided valleys, occasional rapids or small falls, and a few long, narrow lake-expansions. The St. Francis illustrates this. In some cases at least the lake expansions are due to dams of glacial drift across the old pre-glacial valleys.

The courses of the tributary streams, on the other hand, are determined in nearly all cases by the Appalachian folds, and as a result the streams flow in a northeast or southwest direction. The main glacial movement in the region was southeastward roughly parallel to the direction of the lower reaches of the larger rivers and nearly at right angles to the general strike of the folding. Consequently, the main valleys are U shaped, wide, and deep, and most of the tributary streams enter them by falls or rapids from hanging valleys.

LOCAL.

RELIEF.

The area mapped on the Coleraine sheet lies on the east flank of the Sutton Range near its widest part. It includes the foot of the eastern slopes of the range itself, the broken country occupied by the igneous rocks of the Thetford series, and the western edge of the synclinal valley in which flows upper St. Francis River.

The slopes of the Sutton Range appear at the extreme northwestern corner of the map. On the sky-line these hills appear to be very regular and unbroken by any sharp peaks or considerable valleys. The slopes are gentle and of even grade, are covered by an evenly distributed mantle of boulder clay, and are well wooded. They constitute the only good agricultural land within the map-area if we except the narrow alluvial flats along Coleraine River and around Disraeli Bay.

Physiographically, the slopes of the Sutton Range are mature and tending toward old age. Four series of rocks of very considerable thickness, including at least part of each of the Cambrian, Ordovician, Silurian, and Devonian systems, have been eroded from the crests of the anticlines leaving the pre-Cambrian at the surface.

The whole central part of the map-area is underlain by igneous rocks. In contrast to the mature topography of the range to the west these igneous rocks form hills with rugged profiles and steep or precipitous sides, especially where they have been strongly modified by glacial action. In spite of this fact, however, the topographic forms can not be considered young since the area is well dissected by streams which have, for the most part, rather wide valleys. The steepness of the slopes of the hills of igneous rock and their very considerable elevation above the surrounding sedimentary areas must probably be ascribed to the relative insolubility of the secondary minerals like talc and serpentine of which they are composed.

On the other hand, it will be noticed that the depressions in which Breeches Lake and East Lake are found lie in the midst of the igneous rocks and in particularly close relationship to the serpentine. Near by, in Belmina and Caribou mountains, this rock forms elevations rising steeply to 500 and 600 feet above the level of the lakes. The solution of this seeming inconsistency probably lies in the fact that, although serpentine and talc are highly insoluble and not readily further decomposable by weathering processes, yet they are very soft and were very readily eroded by the mechanical action of glacial ice. The basins of

these two lakes, therefore, are believed to be of glacial origin. They are rather deep, the spillways have a rock floor, and the rocky shores descend sharply under the water level, all of which facts tend to corroborate that opinion.

The total relief is not great, the elevations varying from 750 feet above sea level at the surface of Black Lake which lies three-quarters of a mile north of Oak Hill, to 1,820 feet on Caribou Mountain. There are a number of cliffs from 100 to 500 feet in height.

The summits of Belmina Ridge and Caribou Mountain are very rough and uneven. The rock characteristically forms large, rounded, botryoidal masses, and sharp peaks or pinnacles are entirely wanting. This general form is characteristic of all the igneous bodies and is the result of glacial action which is discussed more fully below.

DRAINAGE.

The low divide between the St. Francis on the east and the Becancour on the west crosses the area roughly from north to south. It follows Carineault anticline to Lemay Hill, crosses that hill and the flat to the north, and passes over Caribou Mountain. Thus East Lake and Breeches Lake drain into the Becancour while Coleraine River and Disraeli Bay are part of the St. Francis system. Disraeli Bay and Lake Aylmer which extends for ten miles to the south are expansions of St. Francis River which arises in Lake St. Francis, eight miles to the northeast.

The district is situated so near to the headwaters of these streams that they are, for the most part, too small or intermittent to be used either for transportation or for power development. The St. Francis alone has any considerable permanent flow, and the St. Francis Hydraulic Power Company develops electrical energy at a point one and one-half miles east of the limits of the map. This power is used extensively for domestic and street lighting and in the mines in Disraeli, Black Lake, and Thetford. At the present time a dam is under construction on St. Francis River between Disraeli and Lake St. Francis. This dam will raise the level of Lake St. Francis and insure a good water supply which in the past has sometimes run short in the summer months.

GLACIAL FEATURES.

The highest hills in the region have been glaciated to their summits, and the present topographic forms are, for the most part, the result of glacial action. The slopes of all the larger hills vary notably in steepness, but the more abrupt descents are not found with any regularity facing toward any definite point of the compass. In a general way, the steeper sides face southwest, south, or southeast. This is notably the case on Chalet Hill, Lemay Hill, Carineault Hill, and Drouin Ridge. On the other hand, the high hill of quartzite to the south of East Lake has its steep side facing almost due north.

In the case of the hills of igneous rock it would seem that the location of a particularly steep slope depends on the relative hardness of the rocks and on the relation of the easily eroded serpentine to the direction of ice movement. Chalmers[1] maps the Laurentide ice sheet as having moved toward the southeast and the Appalachian ice as moving north over this general territory, but he does not record finding any glacial striae within the region of the igneous rocks. The writer himself found none within the limits of the Coleraine map-area, and no precise data as to the local ice movements are at hand. Steep cliffs such as that on the south side of Chalet Hill are probably due to excessive lateral cutting into the soft serpentine where the ice was more or less hemmed in between it and harder rocks.

Weathering has destroyed all traces of glacial polishing and grooving of the finer sort on exposed rock surfaces. Erosion has not been great since the retreat of the ice, but the surface of the serpentine outcrops is covered by a thin lateritic layer varying from a few millimeters to an inch in thickness. The color of this layer is about that of yellow ochre with a slightly reddish tinge. The material is very porous and is composed of a mixture of yellow oxide of iron and a clay-like substance which has been formed, presumably, by the breaking down of the serpentine and the abstraction of the silica as outlined by Leith and Mead.[2] The result is that the rounded rock surfaces which undoubtedly appeared dense, green, polished, and striated immediately after the covering of ice was removed, are now coated by a creamy-yellow or red porous, pulverulent layer which retains no traces whatever of any striae or other glacial markings which may have been present.

The attitude of the igneous sheet also has had an effect in producing the nearly vertical outcrop of the serpentine band along the eastern slope of Lemay Hill and Drouin Ridge.

The summits, and the slopes of the igneous hills where they are not precipitous, are covered by small *roches moutonnees* a few feet high and a few feet across. On the western slope of Belmina Ridge near the crest line the surface of the serpentine is in the form of long parallel U or V-shaped flutings, somewhat resembling giant ripple marks, from two feet to twenty feet across and one to two feet deep. These troughs are polished and somewhat grooved in the bottom and suggest the movement of glacial ice in a direction slightly south of east or slightly north of west.

On the eastern side of Caribou Mountain, just north of Kerr Hill, is a small steep-sided well-defined cirque with precipitous walls 400 feet in height. Two or three less clearly defined cirques are to be found elsewhere on the same mountain.

It is hardly conceivable that a cirque could have been developed by a glacier with so circumscribed a feeding ground as the top of Caribou Hill, or that so small a glacier could have existed a sufficiently long time to produce so considerable a cirque as we find. Furthermore,

[1] Chalmers, Report on the surface geology and auriferous deposits of southeastern Quebec: Geol. Sur. Can., Ann. Report, New Series, Vol. 10, Pt. J.

[2] Leith and Mead, Metamorphic Geology, pp. 38-42.

that the glaciation was not local is proven by the fact that rounded boulders of massive white quartzite weighing many hundreds of pounds are to be found today on the highest points of Caribou Mountain, a hill which is composed entirely of serpentine and allied igneous rocks. It is more than probable that the cirque was caused by a small tongue of the main sheet which moved over Caribou Hill as the Laurentide ice mass advanced from the west. The softness and fractured condition of the serpentine rock would render the work of the ice very easy.

There is also a suggestion that the gap between Lemay Hill and Drouin Ridge may represent a pass cut by the ice in the dam of igneous rock which lay across its path. The western slopes of the hill 3,000 feet north of East Lake are dip slopes and of quite even grade. So too, approximately, are the slopes from the east end of East Lake up to Carineault Hill. We may imagine the ice riding up these slopes with comparatively little erosive effect, but where it moved over the edges of the igneous sheet near the summit of the anticline it rapidly carried away the soft igneous rocks and the shattered quartzites.

As already mentioned, Breeches Lake and East Lake probably owe their origin to glacial erosion. The small lake on the summit of Belmina Ridge and Dry Pond on Caribou Mountain are also glacial basins.

Many of the hills and all the valleys are covered by a thin mantle of ground moraine. Even where this is sufficiently thick it is too stony to form a satisfactory soil. On the northern and western sides of Lemay Hill and Drouin Ridge and to the south and southwest of Caribou Mountain are small alluvial fans covering several hundred acres. These fans are made up of coarse gravels and large boulders. The materials are rather poorly assorted, and although brought in and distributed in their present positions by the action of water, it is evident, both from their unassorted character and their topographic position, that they have been transported only a short distance by that agency. The boulders represent many kinds of rock several of which do not occur in place nearer than 25 miles.

CLIMATE.

Dresser[1] states that the average temperature for July and August is 65° F. and for January and February 15° F. In the summer of 1916, however, the thermometer rose to 103° F. on one occasion and stood at over 90° F. on a number of days. In the winter, 20° below zero F., is not uncommon, so the climate may well be described as extreme.

The annual precipitation is about 40 inches; 30 inches of this is in the form of rain, and the balance falls as 90 to 100 inches of snow.

INHABITANTS.

The first settlers throughout this and most of the surrounding districts were English speaking people from the United States or the British Isles. These pioneers were in search of farms, and as the region between Thetford and Disraeli is very rugged with only small isolated patches of good arable land, very few early settlements were made. With the beginning of mining activity in the late seventies and after

[1] Dresser, Preliminary report on the serpentine and associated rocks of southern Quebec: Geol. Sur. Can., Memoir 22, pp. 13-14.

the opening of the Quebec Central Railway in 1880, French speaking people from the St. Lawrence lowlands flocked in. These newcomers soon displaced the few English settlers and now form the entire population. The postmasters and station agents as well as the merchants speak both French and English. In the mines and the country districts French alone is used. English is not taught in the schools.

AGRICULTURE.

As a grain growing region this immediate district has little to which to look forward. The soil is scant and stony and much broken up by rock outcrops. The summer season is not long, but growth is rapid. Seeding is done in May; hay is cut in July; grain and roots are harvested in August and September. Farming methods are still of the primitive sort. The hay crop is cut with the scythe and raked by hand. Many of the small farmers cut their grain with the sickle and bind it into sheaves by hand, tying the sheaf with a wisp of straw as was done everywhere 50 years ago.

Dairying is now the chief source of revenue and will undoubtedly continue to be so. Grass and clover grow well among the rocks and furnish food for a considerable number of cattle. Strangely enough there is no production of butter, local demands being supplied from Montreal, but cheese factories operated on the co-operative plan may be found every few miles.

FAUNA AND FLORA.

All valuable timber has been removed long since, and as several fires have swept the district in the last twenty years no new stand has taken its place. Considerable areas are covered with scrubby birch, poplar, and spruce, or by a dense growth of small alders which makes travelling across country very slow and laborious. Small quantities of pulpwood are still cut from the river bottoms and hillsides which escaped the fires.

With the disappearance of the timber most of the game has also vanished. Now and again a red deer is to be seen, and at rare intervals a black bear is reported in the more unfrequented parts of the hills.

FUTURE OF THE DISTRICT.

The future of the district is bound up with the mining industry of which the nearby asbestos mines of Thetford and Black Lake constitute the outstanding feature. These mines produce more than three-fourths of the world's total output of asbestos, and the value of the present annual production is in the neighborhood of $4,000,000. Several properties have been opened up within the limits of the Coleraine map-area and have been worked from time to time; still others are being opened up at present. A railway three miles in length was built during the summer of 1916 from Coleraine Station to a group of claims on Bisby Ridge, and the foundations for a mill were laid. At the present time, however, there is no production of asbestos from the area mapped.

The present great demand for chromite has resulted in active prospecting over the entire district, and several pits are now in operation and producing a fair grade of ore.

CHAPTER IV.

STRATIGRAPHIC GEOLOGY.

GENERAL STATEMENT.

REGIONAL.

The three ranges of anticlinal hills which cross the Eastern Townships have cores of highly folded pre-Cambrian rocks. Flanking this pre-Cambrian on either side are bands of Cambrian and younger sediments. The synclinal valleys between the ranges are occupied chiefly by Ordovician formations with smaller overlying remnants of Silurian and Devonian rocks, all well exposed in different sections but containing fossils in only a few places.

Three distinct series of igneous rocks are found, clearly separable from one another on the bases of age and lithology. These three comprise: (1) the serpentine series, (2) large batholithic intrusions of granite associated with the Megantic anticline, and, (3) certain volcanics of widespread distribution at the base of the Cambrian. Of these, only the serpentine series is represented within the Coleraine map-area.

The rocks of the serpentine series are altered modifications of normal rocks which originally ranged in composition from dunite through peridotite, pyroxenite, gabbro, and diorite to granite. They outcrop with but few breaks along the entire length of the southeast flank of the Sutton range and come up as scattered bodies here and there through the Stoke and Megantic anticlines.

LOCAL.

Sedimentary, metamorphic, and igneous rocks are all present in the area mapped. In a general way, the igneous rocks form a broad band extending from southwest to northeast, but over considerable areas the surface is so covered by drift that the mapped outcrops of the igneous bodies are very irregular and their true limits indefinite.

The igneous mass, as intruded, ranged from dunite, a very basic rock composed almost entirely of olivine, through peridotite, pyroxenite, hornblendite, gabbro, diorite, and monzonite to granite and pegmatite. The border phases show brecciated, pumiceous, vesicular, and ellipsoidal types. With the exception of the granite, all these rocks have been altered more or less and are now very different in appearance and composition from typical fresh igneous rocks.

In form the igneous body is almost certainly a laccolithic sheet which subsequent to intrusion was folded and in part eroded.

The differentiation which produced most of the various igneous types is thought to have taken place in the sheet itself after intrusion. A later but less extensive and less complete differentiation seems to have modified the nature of the magma still remaining at the source of supply. Subsequently, intrusions of this intratellurically differentiated material in the form of gabbro, pyroxenite, quartz porphyry, pegmatite, and aplite shattered and brecciated the previously irrupted rocks.

In the sheet-like portion of the igneous mass the process of differentiation brought about a definite arrangement of the resulting types, the highly basic dunites being found at the bottom with progressively more and more acid rocks toward the top. The volume of gabbro and pyroxenite is considerable, but the olivine-rich rock is in relatively small amount.

None of the basic igneous rocks were found in an unaltered condition. The dunite, for example, has been completely altered to serpentine in every specimen examined, and it is in serpentine of this origin that the commercially valuable deposits of chromite and asbestos are found. The peridotites also have been largely altered to serpentine, even the pyroxene of the rock having disappeared. Over large areas masses of what was originally pyroxenite have been serpentinized more or less completely. It is worth noting that the serpentine from this source is impure and that valuable mineral deposits have not been found in it.

The precise age of the intrusion can not be determined from the relations observed within this district. The most that can be said is that it is at least post-Farnham, if the black pebbly slates are correctly determined as of that age.

The metamorphic rocks occupy a narrow band along the western side of the igneous mass and are believed to be altered phases of the intrusives. Areally they are of very subordinate importance.

The sediments are believed to range in age from pre-Cambrian to Ordovician. Not a single fossil was found in the area, but the formations have been roughly traced into formations of known age, and the correlations thus made, confirmed by lithologic evidence and structural position, are thought to be essentially correct.

TABLE OF FORMATIONS.

Era	Period	Formation	Character
Quaternary	Recent		Stream deposits
	Pleistocene		Glacial deposits { ground-moraine, outwash
		Unconformity	
Paleozoic	Post-Ordovician	Thetford	Breccia { ellipsoids, true breccia, vesicular rock
			Granite { monzonite, quartz monzonite, granodiorite
			Diorite
			Gabbro
			Hornblendite
			hornblende schist
			eclogite
			Pyroxenite
			Peridotite
			Dunite and serpentine
		Dike rocks	Diabase
			Diorite
			Quartz porphyry
			Granite
			Granophyre
			Pyroxenite
		Igneous contact	
	Ordovician?	Farnham?	Slate, chert
		Unconformity	
	Cambrian?	Sillery? L'Islet?	Slate, sandstone
			Arkose, quartzite, quartz schist
		Unconformity	
Pre-Cambrian		Bennett	Arkose, quartzite
			Quartz schist, mica schist

DESCRIPTION OF FORMATIONS.

PRE-CAMBRIAN ROCKS.

BENNETT FORMATION.

NAME.

The name Bennett has been chosen for this member of the sedimentary series on account of the fact that it is very well exposed on the slopes of the hills near Bennett postoffice, three miles to the north of Belmina postoffice and just off the map.

DISTRIBUTION AND THICKNESS.

The Bennett quartzite is the oldest known formation in the district, igneous or sedimentary. It outcrops over only a small tract in the northwest corner of the area. Its eastern boundary lies approximately in the valley of White River, but it extends to the west for an undetermined distance and makes up the main mass of the Sutton anticline. The hillsides underlain by Bennett quartzite have gentle and regular slopes, for the most part are covered by drift, and afford the best arable land in the district.

On account of the high degree of folding and the limited size of the individual outcrops it was not possible to determine, even approximately, the thickness of the formation. It is almost certainly many hundreds of feet thick.

LITHOLOGY.

The Bennett quartzite is of a light-gray or greenish-gray color, here and there tinged red by iron oxide. On freshly broken surfaces it is decidedly lustrous owing to the presence of much secondary mica. Under the microscope the rock is seen to be made up essentially of small grains of quartz with sutured margins, plentiful shreds and plates of white secondary mica, and varying, but in most cases small, amounts of chlorite. Here and there enough fragments of plagioclase are present to justify the application of the name arkose. The great abundance of mica suggests that there may have been considerable feldspar present in the original sediment and that much of it was arkose.

METAMORPHISM.

The Bennett formation has everywhere undergone extreme regional metamorphism and is folded and crumpled to such an extent that in some places within a space of a foot from five to thirty small plications may be counted. These small crumplings are associated with larger folds from a few feet to a few yards across, and they in turn with larger and still larger folds. As a result of this a high degree of schistosity has been developed, and the rock is, nearly everywhere, a pronounced quartz or sericite schist. Most of the bedding planes have been obscured by the extreme metamorphism. Even the most schistose portions, however, are hard, solid, and compact, a characteristic which serves to distinguish the Bennett quartzite from a paper-thin, fissile phase of the L'Islet formation to be described later.

The fissures and cracks which developed in great numbers during the progress of the folding have been filled subsequently by secondary quartz. The plentiful white stringers of this mineral, which vary from a few millimeters to several feet in width and run in every direction through the schists, are very characteristic of this formation.

STRUCTURE.

The base on which the Bennett was laid down is nowhere visible within the area examined, nor has the upper contact with the L'Islet formation been observed on account of drift covering. The attitude of the beds and the complexity of the folding as compared with the L'Islet make it certain, however, that the Bennett lies unconformably beneath the latter and that it underwent intense folding and metamorphism, probably followed by considerable erosion, before L'Islet deposition began.

CAMBRIAN ROCKS.

L'ISLET FORMATION.

NAME.

The name L'Islet was used as early as 1863 to describe part of the Potsdam formation found in L'Islet county, Quebec.

DISTRIBUTION AND THICKNESS.

The L'Islet formation outcrops in two broad bands which run northeast-southwest parallel to the general strike of the igneous intrusion. The western band lies just to the west of Belmina Ridge; the eastern band appears on the anticline between East Lake and Disraeli Bay and extends to the southern boundary of the map-area. The north end of this anticline is covered by drift, but it is probable that it pitches to the northeast and disappears beneath the younger shales near the eastern border of the area. A small oval outcrop of the L'Islet formation is to be found 1,500 feet to the north of East Lake.

No section was found where a satisfactory measurement of the thickness could be made. The base was not found, and the top is everywhere more or less folded. An estimate on which too much dependence must not be placed puts the thickness at about 1,000 feet.

LITHOLOGY.

The L'Islet formation is made up, for the most part, of massive fine to coarse even-grained silver-gray, gray, or greenish quartzite and arkose, with minor amounts of chloritic or micaceous quartz schist. Here and there the quartzite is almost pure quartz and is nearly white. In many places gradations from coarse to fine-grained layers may be made out clearly in a single two or three foot bed, thus affording evidence as to the original attitude of the beds and the amount of deformation they have undergone.

The typical development of the L'Islet formation is to be seen on Carineault Hill, over most of the broad belt of quartzite extending south from this hill to the map boundary, around Belmina postoffice, and throughout much of the area about Stenson. It is a rather even-grained light-gray rock, weathering almost white. A representative specimen from the roadside one-half mile south of Carineault Hill is an arkrose and has about[1] the following composition: quartz 90%, feldspar 8%, calcite 1%, and a few bits of zircon, magnetite, and muscovite. The larger grains of quartz and feldspar are surrounded by a fine-grained network of small interlocking quartz individuals. Some of these represent original sedimentary grains, but in large part they are cementing material. The large grains as well as the small ones show a sutured texture which indicates some recrystallization.

The schistose phases of the L'Islet formation are found in bands in the more massive quartzite, here and there around the margin of the igneous rocks, and in small areas where dynamic action has been most intense. In general, the sericite schists occur in schistose zones in the quartzite, and the chloritic schists are found more closely associated with the intrusives.

The mica-rich type varies from what is here called a schistose arkose to a quartz-mica schist with an average sericite content of 8% to 10%. In many of the coarser-grained rocks schistosity is not evident in the hand-specimen, and they are described as schistose on account of the presence of from 2% to 5% of mica which is arranged in parallel shreds and shows aggregate polarization over the whole slide. A specimen from the outcrop one and one-half miles southeast of Coleraine shows quartz 90%, sericite 8% to 10%, flakes of chlorite, and a few grains of leucoxene-covered titanite. A schistose arkose found west of the railway is made up of quartz 85%, feldspar 5%, sericite 5% to 8%, chlorite 1%, less than ½% each of magnetite, pistacite, and calcite, and minor amounts of titanite, zircon, rutile, apatite, and yellow and red oxides of iron.

Still another type appears around the eastern border of the oval serpentine outcrop one mile east of Breeches Lake. This rock is a very fine-grained friable paper-thin talcose schist varying in color from slightly pink to silver gray. These fissile schists are of very limited distribution and may be traced into more massive quartzite within a short distance from the intrusion. Presumably they owe their origin to the more intense deformation in the neighborhood of the igneous rock.

Locally over a small area bordering the band of metamorphic rocks west of Chalet Hill, the L'Islet formation is folded and sheared and contains a percentage of platy minerals higher than normal. Stringers and gobs of quartz are very numerous, and the whole appearance resembles that of the Bennett quartzite. It is just possible that this rock may represent a small area of the Bennett formation from which the L'Islet has been eroded. More probably it is a phase of the L'Islet itself which has undergone especially severe metamorphism as

[1] The percentages of minerals given for the different rocks described in this report have been estimated in the thin sections by the help of such diagrams as are given by Johannsen: Jour. Geol. XXV, p. 67.

a result of its nearness to the great intrusive mass to the east. The rock is quite schistose, of a silver-gray to green color, and has a shimmering lustre on fresh surfaces. Under the microscope it is seen to be a chlorite-mica schist with the following average composition: quartz 80%, feldspar 5%, chlorite 10%, sericite 5%, with scattered grains of titanite, magnetite, zoisite, and pistacite.

The quartzite bordering the band of metamorphic rocks to the west and south of Belmina Ridge deserves special mention. For a distance of 100 feet or more from the actual contact with the hornblende rocks it is highly contorted and very micaceous. In many places the contact itself is absolutely sharp and definite. Elsewhere there is a narrow transition zone, but this is nowhere more than a few feet wide and it is always possible to know within less than ten feet whether one is on quartzite or on hornblende schist. A specimen of quartzite taken from the actual contact at a point where it is very sharp shows the following composition: quartz with a few grains of feldspar 95%; muscovite, pistacite, chlorite, and titanite in sub-equal amounts, perhaps 1% to 1½% each, make up the remaining 5%. The rock shows severe crumpling, and in the crumpled zones the quartz is in very finely comminuted grains. Elsewhere the grains are of normal size.

At one or two points along the contact narrow, contorted bands, an inch or two in width, of greenish rock, penetrate the quartzite and themselves contain fragments of quartzite. Under the microscope this green rock is found to consist of quartz 50%, chlorite 35%, pistacite 9%, calcite 3%, magnetite 3%, and a little titanite. The rock is much crumpled. The quartz grains are all small with sutured texture. Augen-like aggregates of the larger grains are surrounded by chlorite-rich aggregates of very finely comminuted quartz and scattered epidote in wheat-like grains. Most of the epidote is associated with the chlorite, and the grains are elongated roughly parallel to the schistosity. The calcite appears in patches in saccharoidal grains.

It is noteworthy that epidote always is to be found in the quartzite near the igneous contacts, but it is very rare in the normal rock. The probable origin of the hornblende schists will be discussed in the chapter on the igneous rocks. Suffice to say here, it is believed that they were derived from an igneous rock of the general nature of a hornblendite and that the narrow green chlorite and epidote-rich bands in the quartzite are altered apophyses of the igneous magma. Slight impregnation of the quartzite by the igneous juices would explain the relatively high content of chlorite in the schists where they border the intrusives.

METAMORPHISM.

The metamorphism which the L'Islet formation has undergone has been dealt with rather fully while discussing the lithology of the different types. Cementation is complete. In all cases the important cementing material is silica, and in most of the slides examined it is the only cement present. Here and there up to two or three per cent of calcite appears, but this is rare. Much of the rock has undergone slight dynamic metamorphism with the result that it is now more or less schistose. Contact metamorphic effects are not shown even around the larger bodies of intrusive igneous rock, but no striking contact metamorphism is to be expected in the case of so quartz-rich a sediment.

STRUCTURE.

Most of the beds of quartzite are from two to three feet in thickness, and gradation from coarse to fine-grained material is visible in many places in individual beds. If it be granted that in such a succession of beds the coarser material will, normally, be laid down first and form the bottom of the bed, the position of the laminae of sorted material goes to support the conclusion drawn from the major structures that the sediments of the L'Islet formation have nowhere been greatly deformed or displaced. In most places the beds dip at angles of from 20° to 45°, but here and there they are nearly vertical.

At the east end of East Lake the quartzite is fine grained and very finely and evenly laminated, the individual laminae being from one-fifth to one-tenth of an inch in thickness.

Along the western side of the map-area the general dip of the quartzites is to the east, but there are numerous small folds with axes running slightly east of north. Some of these folds are made to stand out sharply by the presence of patches of the overlying slate which have been caught in the synclines. In the eastern belt the L'Islet formation is brought to the surface along a pronounced anticline. This is evident from the fact that the top of the quartzite is at an elevation of about 1,200 feet near Stenson, but along the axis of the eastern belt an elevation of 1,500 feet is attained without the appearance of any infolded slates.

The quartzite forming the small area of L'Islet lying near the west end of East Lake is very much shattered, especially for 200 feet around the borders of the mass, and is a splendid example of quartzite breccia. The fragments vary in size from pieces as big as a walnut to huge blocks six feet across. Although considerable movement of the fragments must have taken place, as is shown by the fact that the laminae in neighboring blocks meet one another at all angles, yet there was no injection of igneous material into the fissures. The breccia was recemented by a silica cement and now forms a compact body which shows no bedding planes and is much more massive than the normal quartzite.

Two explanations of the relations of this body of quartzite suggest themselves. Either it is a roll in the floor on which the igneous rocks lie, which has been exposed by erosion, or it is a huge xenolith of quartzite floated up from the floor by the igneous rock which now surrounds it and underlies it. Of these two, the latter seems the more probable explanation. If the mass represents a part of the quartzite floor, we would expect to find the different members of the igneous complex outcropping around the margin in their normal sequence. As a matter of fact, we find only the uppermost member of the series. Further, although the sedimentary roof over the intrusive is typically brecciated, at no place where the known floor is visible does it show any signs of brecciation.

In support of the idea that the mass of quartzite is a xenolith we have the fact that on Drouin Ridge there is a very much smaller mass of similar quartzite breccia which has all the appearance of a xenolith.

No evidence of faulting on anything but a very minor scale is to be found in either the Bennett or the L'Islet formations.

AGE AND CORRELATION.

The distinction between the Bennett and L'Islet formations has been made largely on the basis of mineralogy and metamorphism. As compared with the Bennett, the L'Islet is less sericitic, less crumpled and folded, less schistose, and contains much less secondary vein-quartz. Actual contact between the two has not yet been observed in this district. The correlation with the L'Islet formation of the type area is made on the basis of lithological appearance and stratigraphical position. The beds immediately underlie the shales and sandstones next to be described, and these latter are confidently believed to be the equivalent of the Sillery of the Quebec district.

SILLERY FORMATION.

NAME.

The Sillery formation takes its name from Sillery Cove on St. Lawrence River near the city of Quebec, where it is 2,000 feet thick as described by Logan.[1]

DISTRIBUTION AND THICKNESS.

The Sillery formation underlies a very inconsiderable area within the map limits. In the neighborhood of Stenson village and on the hills one mile east of Belmina postoffice it forms several narrow, elongated bands infolded with the L'Islet quartzite. Two small patches appear along the border of the band of breccia north of East Lake, a third in the breccia on Bisby Ridge, and still others, too small to be mapped, in the breccia east of Coleraine village and on the west side of Oak Hill.

It was found to be quite impossible to determine, even approximately, the thickness of the Sillery formation from the few small scattered outcrops. The probability is that the formation is rather thin.

LITHOLOGY.

The Sillery formation as known within this area is composed of red, purple, or greenish gray mica slates[2] or clay slates with interbedded bands and lenses of red or gray arkosic sandstone, and small amounts of slate hornfels. The variations in color are due to the presence of a greater or less amount of hematite in very minute grains.

[1] The Geology of Canada, 1863, pp. 230-232.

[2] According to Dale, Bull. 586, U. S. G. S., "Slates in which the particles have been merely compressed and cemented by carbonates of lime or magnesia, by kaolin, or by different combinations of iron, and whose fissility, strength, and elasticity are therefore low, may be distinguished as clay-slates from those in which, under metamorphic processes, the kaolin and feldspar have passed into mica. These last may be called mica or phyllite slates. Transitional members where the micaceous matrix is only partly formed may be classed conveniently with the clay-slate group."

Both the purple and the gray phases are typically represented among the infolds of slate near the village of St. Jacques. The "red" slate is a readily cleavable, fissile rock varying in color from purple to maroon. In the small infolds the cleavage is almost vertical and strikes in a direction parallel to the axis of the fold and the elongation of the outcrop. In general the rock is so shattered that bedding is nowhere recognizable.

As seen under the microscope the composition is about as follows: quartz 75%, white mica 15%, chlorite 5%, hematite 5%, and a few grains of magnetite. The quartz and the hematite are in very fine grains and the hematite imparts the color to the rock. Aggregate polarization is quite marked and on the basis of this[1] the rock is classed as a mica slate.

On the hill north of East Lake where the red slates are in contact with the intrusives the rock is, essentially, of the same composition, but chlorite is somewhat more plentiful, in places exceeding the white mica in amount; tiny microscopic "flaser" of larger quartz grains elongated parallel to the long direction of the platy minerals, are numerous; and here and there a grain of pistacite is to be seen. As aggregate polarization is only indistinctly visible, the rock is considered more correctly a clay slate.

The greenish phase of the Sillery is, on the whole, more quartzose than the red phase and is less rich in hematite and sericite. On the other hand, it contains a much greater percentage of chlorite, and this constituent determines the color of the rock. A typical specimen shows quartz 85%, chlorite 15%, a few grains of hematite and magnetite, and scattered flakes of white mica.

The sandy phase is hardly more than represented within the bounds of the area covered by the Coleraine sheet. A few bands and lenses of sandstone from one-half inch to six inches in thickness lie between the layers of red slaty shale in the areas north of East Lake and on Bisby Ridge. It is only where these sandy layers are present and where they extend for some little distance that it is possible to determine the dip of the slates. Pyrite crystals of cubic form up to one inch in size are commonly found in these sandstones.

Here and there along the immediate contact with the intrusive rocks the slates have been baked to a hard, dense fine-grained dark-green, gray-green, or reddish slate-hornfels. This rock shows little or no signs of cleavage and breaks with a sharp, conchoidal fracture. Under the microscope a typical specimen from the ridge east of Brousseau Hill is seen to contain an abnormally high percentage of chlorite with lesser amounts of white mica and grains of red and of yellow oxide of iron. Microscopic "schlieren" of quartz surrounded by a ring of chlorite flakes are visible also.

In fragments of the sandy phase of the Sillery which have been included in a breccia, long needles of biotite are scattered throughout

[1] According to Dale, loc. cit., the distinguishing criterion for these two types of slate is the character of the polarization of the micas. Clay slates have but little, or at best faintly noticeable, aggregate polarization. In the mica slates this phenomenon is quite distinct.

the quartz and chlorite which makes up the mass of the altered rock. The development of the biotite in this connection appears to be genetically connected with the intrusive rock, for it is found only within a few feet of the igneous contact.

METAMORPHISM.

At its type locality in Sillery Cove the Sillery formation consists of shale and sandstone, but in the Coleraine region most of the shale has been altered to slate by the intrusion of the igneous rocks and the subsequent folding. Unfortunately, the metamorphism was so intense that no commercially valuable deposits of slate were formed. The details of the metamorphic effects have been dealt with under the heading of lithology.

STRUCTURE, AGE, AND CORRELATION.

The slates are everywhere intimately folded. In places where they were observed in contact with the L'Islet formation beneath, no evidences of unconformity were seen, but the data were so scant that no conclusion on this point can be worth much.

It will be noted that the Sillery is not mapped everywhere between the Farnham and the L'Islet formations. This may be due, in some places, to a failure to distinguish greenish Sillery slates from overlying black Ordovician slates. On the other hand, it can be explained by supposing that there is an unconformity here, and only a few small remnants of Cambrian slates had not been eroded away when deposition of the Farnham began. Evidences of an unconformity at this horizon are discussed in connection with the Farnham formation.

The tentative correlation of these slates with the Sillery near Quebec rests entirely on the color, lithological character, and apparent stratigraphic position of the beds. Reddish slates correlated with the Sillery do occur between Thetford and Quebec and it is thought that the slates around Coleraine represent Cambrian deposition somewhat farther to the south than has been noted previously.

ORDOVICIAN ROCKS.

FARNHAM FORMATION.

NAME.

The Farnham formation takes its name from the little village of Farnham in southern Quebec, a few miles from Lake Memphremagog and near the international boundary. In the type locality it consists of black shale and limestone[1] with some slate, and on the testimony of the fossils is considered to be of lower Trenton age.[2]

[1] Geology of Canada, 1863, p. 239.

[2] Ells: Geol. Sur. Can., Ann. Rept., New Series, Vol. VII, Pt. J, p. 27.

DISTRIBUTION AND THICKNESS.

Farnham beds occupy a much greater area within the map limits than do the Sillery. They outcrop around the margin of a basin of considerable size lying between Lemay Hill, Belmina Ridge, and Caribou Mountain, and underlie all the southeast corner of the map-area around Disraeli village. A small outlier adjoins the breccia one mile east of Coleraine village, but its extent could not be determined on account of the covering of drift beneath which it disappears.

The lower part of the formation is much shattered by the igneous rocks and the top probably has been removed by erosion. Outcrops are small, and even where the slates are well exposed no bedding can be seen. In the face of these obstacles the thickness could not be ascertained. It is probably several hundreds of feet, and almost certainly the Farnham formation is thicker than the Sillery.

LITHOLOGY.

The Farnham, as represented in the Coleraine area, is made up of black, rusty-black, dark-green, or gray-green argillaceous slate and shale with minor amounts of coarse arkosic sandstone and of dense, hard blue-black chert. In general the rocks are soft and much shattered. In no place, if we except the beds of chert, are they as hard and compact as the underlying Sillery. On the exposed surface, and to a considerable distance beneath it as shown in wells, the slate is everywhere so greatly weathered that it crumbles to thin flakes under the hammer. This disintegration is due to the presence of an abundance of pyrite which appears, in fresher pieces of the rock, as rusty weathered cubes four to five mm. in size. In some places, notably to the east of Disraeli, the pyrite is so abundant that on a specimen as large as the palm of the hand as many as seventy cubes were counted. It is much less abundant in the slate in the basin east of Belmina Ridge, and some beds are almost free from it.

In the bed of Pine River where erosion has cut deeply into the Farnham and where there are several good exposures, black pebbly slates are found. Presumably these slates lie near the base of the formation. The pebbles are not numerous, rarely making up more than 10% of the rock mass, but here and there they are in sufficient numbers to give the rock the appearance of a conglomerate. They are small, rounded, probably by water, and lie embedded in a matrix of black slate similar to that already described. Lithologically the pebbles are of quartz, quartzite, sandstone, and slate, and as far as one can judge from their mineral composition all of them may have been derived from the underlying Sillery and L'Islet formations. Ells[1] described this basal phase of the Farnham under the name "pebbly slate," and Dresser[2] states that in southern Quebec the conglomeratic basal part of the Farnham is as much as 100 feet thick. In that region pebbles make up 25% of the rock in many places.

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1 Ells, R. W.: Geol. Sur. Can., Ann. Rept., New Series VII, Pt. J.

2 Dresser, J. A.: Geol. Sur. Can., Memoir 22, p. 22.

The chert is a very hard amorphous or cryptocrystalline blue-black rock. It occurs in small lenses from a few inches to several feet thick and 15 to 20 feet long, interbedded with the slates.

Locally, thin beds and lenses from one inch to one foot in thickness of coarse-grained gray arkosic sandstone are interbedded between the shaly layers. In many places the thicker sandstone beds show a gradation from coarse to fine materials followed by a further transition to shale or slate. This succession may be repeated several times within the width of one outcrop 20 feet wide.

Under the microscope the sandy phase is seen to be an imperfectly cemented impure arkose or argillaceous sandstone tending toward a wacke. Larger grains of quartz and of partly sericitized feldspar lie in an iron-stained matrix composed of clayey material, secondary white mica, chlorite flakes, leucoxene-coated grains of titanite, and a few small sutured[1] quartz grains. No enlargement of any quartz individuals was observed and cementation is still far from being complete. A typical specimen has the following composition: quartz 55%, feldspar 40%, ferro-magnesian minerals 5%, with very minor amounts of calcite, sericite, magnetite, muscovite, hematite, and chlorite.

The matrix of the pebbly phase appears under the microscope quite like the normal slate. It is perhaps a little more quartzose than the typical Farnham, but it is not so quartz-rich as the green phase of the Sillery already described. There is also much less weathered pyrite present.

Several fragments lying in the matrix of the black pebbly phase were examined carefully. Some of these are composed almost exclusively of chlorite and actinolite, but others are quartz-rich, fine-grained, and very like the quartzose phase of the Sillery. The latter are probably fragments of the Cambrian sediments, the former of a Cambrian or pre-Cambrian igneous rock. Volcanics are known at the base of the Cambrian 20 miles to the west of the map-area, and fragments of these might easily be carried eastward and incorporated in the basal Ordovician beds even if the volcanic series itself did not extend so far. Aggregate polarization is not marked in this phase of the slates.

Three specimens of slate were collected at distances of 80 yards, 15 feet, and 5 feet respectively from the contact between the igneous rock and the slate, one mile east of Coleraine. Immediately adjoining the contact is a narrow band of hornstone. The two specimens taken nearest the intrusion are harder and less fissile than the rock more remote from the igneous mass, which is a typical slate. The mineralogical composition varies but little. In the specimen taken at five feet from the contact it is about as follows: quartz 80%, sericite 15%, calcite 5%, and minute amounts of chlorite, magnetite, hematite, and carbonaceous matter. In the specimen taken at 15 feet calcite is in less amount, and in the normal slate at 80 yards it is not present. Progressively with the decrease in calcite the sericite content rises slightly. Otherwise the rocks show no marked differences.

[1] "Sutured" grains and "sutured" texture are terms used to describe the irregular, interlocking, dovetailing structure found in the quartz grains of certain sedimentary and igneous rocks. "Sutured" texture may arise by recrystallization or by resorption.

A local phase, classed as argillite, is found west of Disraeli Bay. This rock contains 70% gray interstitial material, probably largely quartz, 12% chlorite, 18% magnetite and ferro-magnesian minerals, and a few rods and grains of apatite, calcite, and tourmaline. Neither parallelism nor aggregate polarization is in evidence.

METAMORPHISM.

The Ordovician sediments have been folded and metamorphosed to a degree comparable to that undergone by the Sillery. Both, presumably, were deformed at the same time during the period of deformation which accompanied and followed the intrusions. Valuable deposits of slate are found in the Farnham formation at other localities in Quebec, but the slate of the Coleraine area is quite useless.

STRUCTURE.

Farnham slate lies in what are now both synclinal and topographic basins. The outcrops are remnants of a formation which at one time covered the entire region and which today is widespread toward the southeast but has been completely removed by erosion from the crest of the Sutton and Stoke anticlines. The bedding planes, where seen, dip more or less steeply in general accordance with the dip of the underlying formations.

As has been pointed out already, there are many places around the border of the Farnham formation where the Sillery does not outcrop. In some of these places the contact of the Farnham with the Sillery is masked by drift so that the Sillery may be present but not discoverable. In other localities, particularly at igneous contacts, the slate is so shattered and folded, so injected by igneous juices, and so discolored that any original color distinctions between the Farnham and the Sillery must have been obliterated entirely. On Bisby Ridge, however, the presence of the Sillery below the Farnham is shown in a large xenolith or roof pendant of red slate and sandstone. This xenolith, although surrounded by igneous rock and itself much shattered, was large enough to preserve its original characteristics.

The absence of the Sillery formation in many places coupled with the presence of the pebbly, conglomeratic basal phase of the Farnham tends to support the conclusion that there is an unconformity between the two formations, and that during this interval most of the Sillery was removed.

The Farnham formation is the youngest consolidated sediment in the region and unconformably underlies the loose Pleistocene deposits.

AGE AND CORRELATION.

The complete absence of fossils over the entire area under discussion makes the problem of correlation one of lithology, stratigraphic position, and horizontal tracing of beds, and leaves it at best in an unsatisfactory state. The black slates are correlated with the Farnham of southern Quebec largely on the strength of the pebbly, conglomeratic basal phase.

PLEISTOCENE ROCKS.

The Pleistocene deposits have been discussed sufficiently in Chapter II. Patches of ground moraine are found, here and there, over most of the area. To the east and southeast of Coleraine the mantle of glacial drift is continuous, and no rock outcrops were discovered. Where the drift is so thick and so continuous as to hide the underlying rock completely, this fact has been indicated on the areal map. No attempt was made to interpolate geologic boundaries across some of the larger drift-covered areas.

The moraine itself is stony but is rather evenly distributed over the slopes. The tops of most of the hills of igneous rock are bare except for scattered erratics. Around the margin of Disraeli Bay there are a few hundred acres of flat-lying alluvial, stream deposits.

CHAPTER V.

IGNEOUS AND METAMORPHIC ROCKS.

THE IGNEOUS ROCKS.

GENERAL STATEMENT.

NAME.

The name "Thetford series" as applied to the igneous rocks of the serpentine belt of eastern Quebec, is taken from the town of Thetford, ten miles north of the boundary of the area covered by the Coleraine sheet. Thetford is the center of a great asbestos-mining industry, and the more basic members of the igneous series are excellently exposed in the huge quarries within the town limits.

DISTRIBUTION.

The outcrops of the igneous rocks form two very irregular bands which are roughly parallel to one another and cross the area from northeast to southwest. The western of these two bands may be traced with the same general strike for many miles in either direction beyond the map limits. The eastern band, although less well marked, extends for a number of miles to the northeast.

The individual members of the Thetford series appear, at first sight, to be scattered rather promiscuously over the area occupied by the igneous rocks, but where the topography is such that the attitude of the intrusive mass causes them all to be exposed within a short distance, it may be seen that they occur in a definite order. This sequence is well shown on Lemay Hill and on the small ridge northwest of Brousseau Hill, where the most basic members lie beneath the phases of intermediate composition. The more acidic types, including granodiorite, monzonite, and granite, appear as dikes and irregular masses intruding the previously intruded basic rocks.

Most of the rocks of the Thetford series are more basic than granodiorite. Monzonite, granite, and aplite appeared as the last phases of the differentiation which produced the different types, and are present only in minor amounts.

For purposes of mapping in the field six phases were distinguished macroscopically, as follows: (a) serpentinized dunite and olivine-rich peridotite; (b) serpentinized pyroxenite and olivine-bearing pyroxenite containing small masses of serpentinized pyroxene-rich peridotite; (c) pyroxenite, fresh or only slightly altered; (d) gabbro with minor amounts of diorite; (e) granite; (f) the brecciated contact phase of the series.

The basic members of the series have been named in accordance with the following mineralogical composition as determined under the microscope by inspection and estimation:

100%-99% pyroxene.....pyroxenite
Pyroxene with 1%-5% olivine...olivine-bearing pyroxenite
Pyroxene with 5%-95% olivine.peridotite
95%-100% olivine.....dunite

DESCRIPTION OF INDIVIDUAL IGNEOUS TYPES.

SERPENTINIZED DUNITE AND OLIVINE-RICH PERIDOTITE.[1]

NAME.

The dunites and peridotites of the Thetford series are no longer fresh and in most places are recognizable only through the secondary minerals present. These rocks have been mapped under the name of "serpentinized dunite and peridotite," but under the microscope they show little or nothing but serpentine and for convenience of reference will be referred to in this paper as serpentine rocks.

DISTRIBUTION.

Serpentine rocks are found in a number of places scattered over the area, but nowhere do they underlie any considerable territory. The largest known mass lies at the foot of Caribou Mountain along the eastern and southern sides. The valley between Caribou Mountain and Oak Hill, as well as part of the gravelly apron between Caribou Mountain and the three peaks on the county line to the south, are probably underlain by serpentine.

An almost continuous band of serpentine may be traced for two and three-quarter miles from a point southwest of Coleraine to a point south of East Lake. For a mile and a half beyond the lake, drift covers the probable contact, but the serpentine again outcrops near the northeast corner of Breeches Lake. The band then cuts across the point between the legs of the breeches and appears on the small island in the lake and on the flat to the south of Chalet Hill.

A large body of serpentine with some pyroxenite outcrops at the south end of Breeches Lake and extends beyond the southern limits of the map. This area was not examined in any detail.

Five small patches or dike-like masses of serpentine are associated with the more easterly band of L'Islet quartzite. The most southerly of these is somewhat oval in shape and is to be found about a mile south of the road from Disraeli to Breeches Lake. Three other outcrops of dike-like dimensions lie east of the railway near Carineault Hill. The fifth is a small drift-bounded outcrop one mile southeast of Coleraine village.

Small scattered and irregular outcrops of serpentine are present among the more acidic rocks on Bisby Ridge, Belmina Mountain, and Caribou Mountain.

LITHOLOGY.

On fresh fracture-surfaces massive serpentine varies in color from dark olive green to dull greenish black. Slickensided surfaces are of a much lighter grass-green color and many of them are highly polished or striated. On well-weathered surfaces the rock is of a dirty creamy color locally tinged with red. Only rarely is pure serpentine which has been derived from dunite or peridotite of a distinctly red hue. In a few places the rock is very fine grained, black, and soapy to the touch, but in most places it is of medium grain and does not suggest talc except on slickensided surfaces.

[1] This rock type, under slightly different name, appears on map as number 1.

Serpentine rock is everywhere very soft, and in many places it is considerably broken up. Much of it has resulted from the alteration of a pure dunite, but in nearly every specimen examined the olivine has disappeared completely. Only the irregular network of crystals of chromite or magnetite or both, or of veinlets of chrysotile lying in nearly isotropic serpentine, points to a derivation from dunite. Suggestions of a few scattered crystals of pyroxene, also altered to serpentine, can be made out here and there by the "lattice" or "gitter" structure of the secondary minerals. Where the pyroxene exceeds 5% in amount but makes up less than 95%, the rock is to be considered as a peridotite, olivine-rich or pyroxene-rich as the composition dictates.

The serpentine itself occurs in several forms: (a) more or less fibrous masses with or without magnetite; (b) in fine, granular, dense, dovetailing aggregates free from all signs of cleavage or of fibrous character; (c) in isotropic plate-like masses; (d) as chrysotile.

Variations in the composition of the dunite may be seen clearly under the microscope in specimens from the serpentine area one and one-half miles east of Breeches Lake. This mass of igneous rock is composed entirely of serpentine and has somewhat the appearance of a triple sill dipping to the east. The upper body is 25 feet thick, the middle one about 10 feet, and the lowest 175 feet or more. All three lie superimposed directly one upon the other. The two upper layers are intrusions of much smaller volume which probably succeeded the main intrusion of peridotitic magma that makes up the bottom sill. A specimen taken at 75 feet below the top of the main sill shows serpentine 99%, carbonates 1%, with a few small grains and dust-like particles of magnetite and an occasional grain of picotite. Another specimen taken at 25 feet below the top of the same sill, that is, 50 feet above the previously described specimen, shows serpentine 98% and 2% of carbonates. Ten feet higher than this the carbonate has increased to 3% and occurs in patches fairly evenly spaced out from one another and showing a semblance of crystal outlines. The suggestion is that the carbonates represent scattered pyroxene crystals. If this be true, the pyroxene progressively increases in amount from the bottom to the top of the sill. Throughout the mass alteration is complete, and the original nature of the rock is suggested only by the secondary products.

On top of, and around the base of, Caribou Mountain the different types of serpentine are well shown, and it is possible to correlate the color of the weathered rock with its original mineralogical composition. The redder the weathered product, the higher the content of pyroxene in the original rock.

A specimen of soft white-weathering serpentine derived from a dunite and taken from the south slope of Caribou Mountain, is composed of 99% or more of serpentine with a few grains of magnetite and picotite and small unaltered remnants of olivine. There are only the slightest traces of original pyroxene. The minute quantity of magnetite present in this type of rock indicates that the olivine was of the iron-free variety. It must not be inferred, however, that this is true of all the dunites of the region. A great deal of magnetite is present in the pure serpentine found on the south side of Chalet Hill, and as there was no pyroxene in the original rock, so far as known, and the magnetite clearly appears to be of secondary origin, this fact points to an iron-rich olivine.

A yellow-weathering variety of the serpentine also found on Caribou Mountain is composed of about 96% serpentine and unaltered olivine remnants with 4% of partly altered automorphic pyroxene crystals. The magnetite which once was present has been oxidized completely to yellow oxide of iron.

A bright brick-red phase of the serpentine found near the top of Caribou Mountain is composed of the same minerals, but here the amount of pyroxene in the unaltered rock was as high as 10%. It seems a fair inference, therefore, that the depth of red coloring in the altered rock depends directly upon the amount of pyroxene present in the unaltered rock. Most of the olivine was of the magnesium-rich, iron-free or iron-poor variety, and the content of oxidized iron which gives the rock its color varies with the content of pyroxene. As might be expected from this, the altered pyroxenites are of a very conspicuous red color, much more intense than is found in any of the altered dunites or olivine-rich peridotites. The serpentine found on Oak Hill shows no evidence of any original pyroxene. The olivine, however, was abnormally rich in iron and as a result the serpentine is of a pale-yellow color not common in the secondary derivatives from dunite.

A thin section of a specimen from the prospect pit near the east end of Brousseau Hill is so cut as to show the contact of two igneous types, both now so completely altered that the original minerals are suggested only by the structure of the serpentine. Carbonation has progressed to a considerable degree, but recrystallization of the carbonates is far from complete. The composition is, approximately, serpentine 60%, carbonates 40%, and a few grains of magnetite. The rock has been fractured, and chrysotile fills the cracks thus formed. Subsequent movements have twisted and sheared the chrysotile fibres. The carbonate varies from colorless to brownish, the latter variety being noticeably pleochroic. In general, the section may be divided into two parts. In one of these is serpentine with negligible amounts of carbonate; in the other partially recrystallized carbonate with scattered grains and fibres of serpentine. It appears certain that the two parts represent two rock types, the carbonate-rich phase probably being the altered equivalent of a pyroxenite and the carbonate-poor phase an altered dunite. All evidences of conditions at the igneous contact have been obliterated by the processes of alteration.

In another interesting slide the brown, cloudy, impure carbonate masses have the form of more or less perfect rhombohedrons, each surrounded by a uniform border of fibrous serpentine with the long axes of the fibres perpendicular to the border of the carbonate. The colorless, clear carbonate masses are without any enclosing border of chrysotile.

HARZBURGITE.

The typical wall rock of the upper quarry at the south end of Belmina Ridge is an enstatite peridotite or harzburgite. It is gray green in color on freshly broken surfaces and medium coarse grained. It is very tough and when broken presents rough, hackly surfaces on which large crystal faces are visible here and there. The texture is hypautomorphic granular and might be described as "pseudo-porphyritic," indicative of the larger pieces of pyroxene lying in a matrix of finer-grained olivine.

In composition the harzburgite shows olivine 90%, enstatite 10%, with accessory picotite and magnetite, and secondary magnetite and serpentine.

In the unshattered rock alteration to serpentine is just commencing, the progress of the alteration being marked out by the threads of serpentine which traverse the crystals of enstatite and olivine. Where the rock has been shattered the original minerals of the harzburgite have disappeared completely. The major part of the altered rock is serpentine which appears to be almost isotropic under crossed nicols. The enstatite crystals have been replaced by bastite pseudomorphs and the olivine by fibrous chrysotile and strings of tiny grains of magnetite. The bastite pseudomorphs extinguish in a position parallel to the cleavage of the original enstatite. This would seem to indicate that the serpentine fibres grew in either parallel to the cleavage or more likely at right angles to it.

Of the original minerals picotite and a little magnetite alone remain. Secondary iron is present as minute flakes of hematite which give a decided purplish color to the soft, soapy, friable rock.

A similar harzburgite is to be found on the small round hill one mile southwest of Coleraine village.

CHROMITE IN THE SERPENTINE.

Chromite occurs in scattered grains in serpentine of all derivations, but it is found in minable quantity only in serpentinized dunite. In every case where a considerable quantity of chromite was observed there is a band at least a few millimetres in width around the immediate border of the chromite in which alteration to serpentine is complete. Farther distant from the chromite considerable amounts of unaltered olivine may remain.

METAMORPHISM.

The general character of the alteration which the dunite and peridotite undergoes has been dealt with rather fully while describing the various types of serpentine. This is unavoidable since only the much altered equivalents of the original rocks are now to be found. As a result, a discussion of metamorphism under a separate head is almost superfluous.

That the process of alteration is not everywhere equally complete, and that the stage of advancement of the process varies widely within short distances, is well illustrated in the exposures around Breeches Lake. A specimen from the small island in this lake shows a mass of pale-gray serpentine with interpenetrating veinlets of chrysotile and scattered grains of magnetite, the latter being in part secondary, in part primary. Some of the primary magnetite grains show skeleton crystals and reaction rims. In a specimen from the serpentinized mass on the point just to the east of the island serpentine makes up only 60% of the rock, the remainder being unaltered olivine with a little magnetite. Both rocks were, originally, hypautomorphic-granular holocrystalline coarse-grained dunites.

The alteration from olivine to serpentine entails a very considerable increase in volume and the effects of this expansion are clearly evident in the serpentine mass itself which is shattered, sheared, and slickensided over large areas. It is in such zones of shattered rock that most of the long-fibre asbestos of commerce is found.

The serpentinization of these basic rocks is, primarily, a matter of hydration, and as such has been thought of formerly as having proceeded from the surface downward. If this supposition be true, the depth to which complete alteration has reached seems extraordinary because no marked difference can be observed between the rocks found at the surface and those revealed by the drill at depths of 500 feet and over. It is hoped that a careful study about to be undertaken of a number of specimens obtained at different depths from the present surface and through a considerable range, may throw some light on this problem. The mineralogical association in a number of quarries points strongly to thermal waters as the cause of the serpentinization.

A detailed study of the mineralogy of the whole Thetford region is now nearing completion and will shortly be published by the Geological Survey of Canada. Sixty mineral species have been identified from the district.

ORIGIN AND STRUCTURE.

The dunites and peridotites, in common with all other members of the Thetford series, are of intrusive origin. Wherever the dunites are found associated with the more acidic types, they lie stratigraphically beneath the latter or more or less completely surrounded by them. The first condition prevails near East Lake, the second in Brousseau Hill. Where the relations between the igneous rocks and the sediments which have been intruded can be made out clearly, it is seen that the serpentine lies upon a floor of L'Islet quartzite. The general structural relations of all the igneous types will be discussed below.

SERPENTINIZED OR PARTLY SERPENTINIZED PYROXENITE AND PYROXENE-RICH PERIDOTITE.[1]

NAME.

This phase of the igneous body does not form so sharply defined a petrographic type as do the dunites, but it makes up in volume what it lacks in definition. It may be considered to include all the serpentized rocks of the differentiation series which originally contained less than 60% of olivine. As a matter of fact, these rocks make up the largest individual igneous masses in the region, and since the original unaltered rocks differed considerably in mineralogical composition, their altered equivalents vary much in appearance.

DISTRIBUTION.

Rock of this igneous type underlies most of Belmina Ridge and Caribou Mountain and is present in large masses on Oak Hill and north of Bisby Ridge. Smaller bodies are found near Chalet Hill, Carineault Hill, and Brousseau Hill, and on the point in Breeches Lake.

[1] This rock type, under slightly different name, appears on map as number 2.

LITHOLOGY.

In treating of the lithology of this type it will be convenient to consider together the rock of Belmina Ridge and the rock of the area north of Bisby Ridge. In both of these areas much of the original rock was a peridotite with a fair amount of olivine. On Caribou Mountain and on Oak Hill, on the other hand, the rock was a relatively pure pyroxenite, an olivine-bearing pyroxenite, or a pyroxene-rich peridotite. Both types have been more or less completely serpentinized and they weather to a brick-red color which is in strong contrast to the creamy, grey, whitish, or pinkish weathered surface of the olivine rocks.

"Nail-head" structure, so named by Dresser, is frequently seen in the pyroxene-rich rocks. On exposed surfaces the olivine and serpentine wear away more rapidly than the tougher pyroxene with the result that the individual crystals or crystalline grains of pyroxene stand out on the surface and give the rock a nubbly appearance.

In much of the serpentine the absence of any considerable quantity of secondary magnetite is noteworthy. The serpentine itself is of two types. One type has more of the chlorite molecule associated with it and is somewhat green in color with interference colors varying from dull brown to deep chlorite blue. The texture is coarse, and the serpentine has replaced pyroxene crystals whose outlines still can be made out faintly. The other type of serpentine is colorless to greyish and has a higher interference color. The texture is much finer, in places being spherulitic, fibrous, or spheroidal.

BELMINA RIDGE TYPE.

On exposed surfaces the serpentines of Belmina Ridge have a rusty-red weathered zone which varies from the thinness of paper to as much as three-quarters of an inch in thickness. The weathered material is very porous and friable and crumbles easily under the hammer. It is composed largely of limonite with small amounts of the dehydrated oxides of iron.

Underneath the weathered zone freshly broken surfaces of the massive rock are of a deep olive-green to greenish-black color. Where movement has taken place and the surfaces are slickensided, they are polished and striated and of a brilliant apple-leaf-green color. Near the south end of the ridge small masses of minutely fractured and sheared serpentine in which oxidation of the iron has proceeded to a considerable depth, are of a purple tint.

The outlines of primary pyroxene crystals, now represented by bastite pseudomorphs, may be seen on any freshly broken surface. These crystals are scattered only here and there in the duller more granular olivine of the olivine-rich peridotite which is present in small masses in the pyroxene rocks, but in the pyroxene-rich peridotite they are found very plentifully with the olivine in the interstices. In rare instances the pyroxene crystals appear to make up the whole mass of the rock, no olivine being visible to the unaided eye.

The olivine-rich peridotite just mentioned appears here and there in small masses surrounded by less completely serpentinized rock which has a much higher pyroxene content. The rock in the small out-

crop near the school house on the Belmina road is very rich in olivine; so also is the rock in the vicinity of the prospect pits at the north end, and around the larger quarries at the south end of Belmina Ridge. These quarries were operated for some months and a considerable quantity of asbestos was obtained from a shattered zone in a pocket of serpentinized harzburgite. Unfortunately, the peridotite is surrounded by rock much richer in pyroxene and devoid of asbestos fibre, and to such pockets must be attribued the failure of many promising prospects to develop into steadily producing quarries. These olivine-rich pockets have been fully described in the discussion of serpentine rocks.

The partly serpentinized rock north of Brousseau Hill is dark green, hard, and tough, and shows the outlines of numerous coarse crystals. Originally it contained about 20% olivine, 10% augite, and 70% enstatite. Serpentinization has proceeded until the rock is approximately 50% altered, the olivine being affected most and the augite least. The pyroxenes enclose grains of olivine and magnetite thus producing "poecilitic" structure. On the weathered surface this rock shows distinct "nail head" structure. The type grades into other rocks containing less and less olivine until the quantity present is so small that it can be considered little more than accessory.

Underneath the serpentine mass on the south side of Chalet Hill is a small body of partly serpentinized diallage-olivine rock. The greater part of the rock is diallage which has altered to dark, iron-stained talc along several bands where shearing zones have broken the crystals. Only a few fragments of olivine remain, most of the grains having been replaced entirely by serpentine and magnetite. What appears to be a similar, although much less deformed and altered, rock is to be found in the body of pyroxenite just east of the outlet of Breeches Lake. Serpentinization is just beginning, and the rock is composed of diallage 95%, olivine 5%, and a few grains of magnetite.

A specimen from the point in Breeches Lake is instructive since it shows the order of alteration of the ferro-magnesian minerals. In a rock originally containing diallage 40%, olivine 35%, and enstatite 25%, the diallage is still quite fresh, 80% of the olivine has gone over to serpentine, and 20% of the enstatite is replaced by bastite.

In some places the alteration of true pyroxenite is very complete but in others it is only partly completed. It is noteworthy, however, that where monoclinic and orthorhombic pyroxenes occur in the same rock, the alteration of the orthorhombic form is always well advanced before the monoclinic variety is attacked. In many places the orthorhombic mineral has all but vanished to chlorite, serpentine, actinolite, and other secondary products, while the monoclinic form is still comparatively fresh.

A very complete case of alteration of a pyroxenite is to be found on Bisby Ridge east of Brousseau Hill. On the weathered surface the rock is white and so soft that a small hammer may be driven into it easily to a depth of an inch or more. Under the microscope the rock is seen to be composed of talc 85%, carbonates 14%, magnetite, chromite, picotite, together 1%. The iron has been removed almost completely. This altered phase adjoins fresh, unaltered pyroxenite and

presumably is an altered phase of that rock, although this has not been proven. The alteration was made possible by the extreme shattering which the original rock underwent along a line of disturbance probably caused by the intrusion of a neighboring mass of granite.

A similar very impure soapstone containing leucoxene, titanite, titaniferous magnetite, white mica flakes, 14% of chlorite and serpentine together, a few grains of opal, and 85% talc is to be found along the borders of the dike-like mass of serpentine east of Carineault Hill. In this case the arrangement of the magnetite and chlorite indicates folding, and some fracturing is apparent.

CARIBOU MOUNTAIN AND OAK HILL TYPE.

Many of the serpentinized rocks of Caribou Mountain and of Oak Hill were originally composed almost exclusively of pyroxene. They too weather to a rusty, brick-red color, but serpentinization has not proceeded so far as in the case of the rocks of Belmina Ridge. On freshly broken surfaces the rock is coarsely crystalline, olive green in color, and to the unaided eye appears in most specimens to consist of pyroxene only. The pyroxene crystal-faces vary from a few millimetres to as much as two or three inches in length. The rock is exceedingly hard and tough and resists erosive agencies better than the softer rocks already described. Serpentinization has begun here and there between the crystals of pyroxene and in the olivine granules. Thin films of serpentine in some of the cleavage cracks of the pyroxene mark the further progress of the alteration.

The dynamic alteration of a pyroxenite, assisted by weathering and possibly also by hydrothermal agencies, is well illustrated in the dikes in the gabbro mass on the west slope of Chalet Hill. The pyroxenite has been sheared and crushed with the result that most of the pyroxene has been altered to chlorite and uralite. What pyroxene remains is shredded and fractured. Into the mass has been intruded a magma which must have carried alumina, for along the contact there is an extensive development of epidote and zoisite. A small amount of these minerals also developed throughout the shattered pyroxene.

The intruding dike or vein, probably the former, is composed of small angular grains of quartz or feldspar. The grains are probably highly siliceous in composition, but certain determination was not made on account of their fineness. Whether dike or vein, it carried in alumina since it seems unlikely that there could have been a sufficient amount of this element present in the pyroxene itself to produce the very considerable amount of epidote found.

A neighboring variety of pyroxenite which originally contained a feldspar and a few scattered grains of accessory olivine along with diallage and some other ferro-magnesian mineral now completely altered to chlorite, is represented by actinolite, chlorite, zoisite, epidote, and 30% unaltered diallage. This rock too has been intruded by an acidic magma.

OLIVINE-BEARING WEBSTERITE.

Still another variety found on the northern slope of Oak Hill may be called an olivine-bearing websterite. It consists of diallage 15%, orthorhombic pyroxene partly serpentinized and chloritized 82%, olivine, now replaced by serpentine, 3%, and a number of crystals of zoisite and magnetite. This is an unusual association in which to find zoisite, a mineral which is not common in rocks so rich in pyroxene. Possibly it replaces crystals of feldspar. This variety was not found elsewhere in the area than in this one location.

STRUCTURE.

The relation existing between the more acid pyroxenites and the dunites already described is well shown on Oak Hill. Along the boundary between the two types and especially toward the southern end of the hill the coarsely crystalline, rough, hackly pyroxenite has intruded and somewhat brecciated the finer-grained olivine rock. Pyroxene crystals as much as one-half inch in length are found plentifully in small ribbon-like dikes one or two inches across, and although this shows that the intrusion of the two rocks was not simultaneous, yet in such basic magmas the fact that the pyroxene crystals are very coarse does not prove that the dunite was consolidated before the pyroxenite was injected. As crystals of equal size have been observed[1] to form in basic slags poured from a furnace, we have no means of judging of the lapse of time between the successive floods of igneous material. The probability is that the interval was very short and that the process of intrusion was essentially continuous.

In the brecciated zone the dunite appears as globular, ellipsoidal, or irregular masses varying from the size of an egg to the size of a human head. These masses are surrounded by a network of small pyroxenite dikes. The brecciated zone is from 30 to 40 feet wide, for although stringers of pyroxenite cut through the dunite over most of its extent, noticeable brecciation occurs only along the borders. This, of course, might be expected, for the chief force of the intrusion would be exerted only around the edges of the dunite mass.

Suggestions of a similar brecciated dunite were seen on Brousseau Hill and near East Lake, but nowhere else was the evidence so conclusive as on Oak Hill.

PYROXENITE.

DISTRIBUTION.

Pyroxenite is of rather wide distribution. A "U" shaped aureole of this rock is found at the southern end of Belmina Ridge; a narrow band parallels the serpentine from Breeches Lake to near Coleraine; a large mass forms the southern and eastern slopes of Oak Hill, and the small outcrop north of Chrome siding probably indicates a continuation of this body to the northward; a narrow band cuts across the small ridge one mile north of Brousseau Hill; and much of Brousseau Hill itself and of Bisby Ridge are composed of pyroxenite.

[1] Johannsen, A., Personal communication.

LITHOLOGY.

Pyroxenite differs from the serpentinized pyroxenite just described in the fact that it is essentially fresh and unaltered. This condition appears to be due to the fact that the rock is of more siliceous composition, and as it contains little or no olivine serpentinization is little more than in its incipient stages. The serpentinized rocks lie under the fresher pyroxenite, but serpentinization has taken place not because of their position but because of their composition.

Both in the hand specimen and under the microscope this rock is much more constant in appearance than any of those previously described, and it constitutes a sharply defined petrographic type containing nothing but pyroxene as an essential mineral constituent.

Proxenite is greyish green to olive green in color on the weathered surface instead of the rusty-red color so characteristic of the rocks where serpentinization has proceeded to a considerable extent. It is exceedingly hard and tough and good hand-specimens can be obtained only by dint of much patience and labor. For the most part it is coarsely crystalline, crystal faces up to two or three inches in length being very common. On the freshly broken hackly surfaces the color is bronze green to dark, apple-leaf green.

"Nail-head" structure is common among the coarsely crystalline pyroxenites. Under the microscope the pyroxene is seen to be diallage in most specimens, but enstatite is present in some localities.

ENSTATITITE.

A specimen taken from Bisby Ridge near the eastern boundary of the map is a dark-green very hard and tough coarsely crystalline hypautomorphic-granular rock composed essentially of enstatite. Along the cleavage cracks alteration to actinolite and serpentine is just commencing. Little patches of serpentine here and there through the pyroxene probably represent accessory grains of olivine. True enstatitite was found only in this one locality.

DIALLAGE BEARING ENSTATITITE.

A rock composed of enstatite 92%, diallage 8%, is found on the southern slope of Oak Hill. It may be called a diallage-bearing enstatitite. The enstatite is partly altered to talc and along the cleavage planes the diallage is commencing to change to chlorite and talc.

WEBSTERITE.

On the eastern slope of the hill one mile southwest of Coleraine village a tough, hard grey-green hypautomorphic-granular rock was found. It is composed of approximately equal quantities of diallage and enstatite. On the whole it is still comparatively fresh, but the enstatite has undergone much greater alteration than the diallage. Most of the enstatite crystals are euhedral, lying embedded in the diallage, and 75% of them show more or less alteration to bastite, scaly serpentine, actinolite, and magnetite. Where enstatite individuals are

in contact with diallage there is a well defined border of actinolite needles and flakes. No border is found between two diallage or between two enstatite crystals. The actinolite needles grow out into the enstatite normal to the edge of the neighboring diallage, and here and there a few needles pierce the border of the diallage itself.

ENSTATITE-BEARING DIALLAGITE.

A partially altered rock of this type is found at the west end of Drouin Ridge. Originally it was composed of diallage 75%, enstatite 25%, and accessory magnetite. The diallage is still comparatively fresh, showing only the first stages of alteration. The enstatite is largely altered to serpentine, chlorite, actinolite, and pistacite. The amount of pistacite is unusually high, making up about 8% of the partially altered rock.

DIALLAGITE.

The typical pyroxenite of the region is diallagite and it is well exposed on Drouin Ridge. This rock is of coarse but uniform grain with individual crystal faces up to two centimetres in length. It is dark green in color with, here and there, a slight tinge of serpentine green due to partial alteration. The rock is very tough.

Under the microscope it is seen to be holocrystalline hypautomorphic-granular in texture and composed, originally, of nearly 100% diallage with two or three crystals of accessory orthorhombic pyroxene. Alteration has begun here and there throughout the rock and its progress is marked by needles of actinolite, flakes of chlorite and of colorless amphibole, and small patches of calcite.

Still another variety of pyroxenite is to be found in the flat one and one-quarter miles southeast of Coleraine. Megascopically the rock is indistinguishable from the diallagite just described, but under the microscope it is seen to be composed of diallage 50%, augite 35%, and orthorhombic pyroxene 15%. The diallage and augite are comparatively fresh, but the orthorhombic pyroxene is almost completely altered to bastite, actinolite, iddingsite, hematite, and magnetite.

AGE.

Some at least of these comparatively hard, tough fresh green pyroxenites are younger than any of the rock types already described in this chapter. In the zone of brecciated peridotites on Oak Hill stringers of coarsely crystalline greenish-grey pyroxenite cut both the fine-grained olivine rocks and the coarser red-weathering pyroxenic dikes. Thus, in this hill three periods of irruption are represented, and the same condition may be seen on Brousseau Hill. The intrusions probably followed very rapidly one after the other, each succeeding magma being more siliceous than its predecessor.

GABBRO-DIORITE.

DISTRIBUTION.

Areally, gabbro-diorite is the most important member of the igneous series in this region. It occupies a considerable area between Breeches Lake and East Lake, and a narrow band runs at least part way along

the eastern flank of Belmina Ridge. Another band parallels the serpentine from near East Lake to Coleraine and reappears from under the alluvium at the foot of Oak Hill and on the large hill northeast of the village. It is probable that the valley through which the road and railway pass from Coleraine to Chrome Siding and Black Lake is underlain by gabbro, but this can not be certainly known on account of the heavy covering of drift. A small oval outcrop in the middle of the alluvial flat south of Caribou Mountain may indicate a much larger body of gabbro whose extent can not be determined. Gabbro is exposed also in a narrow band along the south side of the ridge one mile northwest of Brousseau Hill.

In previous descriptions of this general region considerable areas of diabase have been mentioned. As used in this paper, diabase implies a rock with or without olivine, having laths of basic feldspar, labradorite or anorthite, embedded in augite which extinguishes simultaneously over considerable areas of the section. Diorite, on the other hand, is a rock whose feldspar is predominantly oligoclase or andesine. The two rocks are distinguished on the basis of the feldspar present rather than on the basis of the ferro-magnesian mineral present. A diorite may have ophitic texture. Hence, although all diabases have ophitic texture, all rocks with ophitic texture are not considered diabase.

Diabase does occur in a few small dikes which are considerably younger in age than the main body of igneous rock, but the writer found no mass of diabase which could be considered as occupying a place in the Thetford series between the pyroxenites and the diorites. In all the feldspar-pyroxene rocks diabasic texture is conspicuously absent.

LITHOLOGY.

The gabbro-diorites vary widely in appearance. A few small masses were found in which the individual grains of feldspar and pyroxene were as much as one centimeter in length. In such a rock the feldspar is dark grey and the pyroxene olive green. The rock itself is comparatively unaltered, hard and tough, and has an attractive mottled appearance.

Most of the gabbro is of medium-coarse grain, the pyroxene and feldspar individuals being a few millimeters in size but quite readily distinguishable by the unaided eye. The rock is very light grey in color, tending toward white on account of the high percentage of feldspar present. The pale-green pyroxene is not in well-formed crystals, but where it is plentiful it imparts a greenish cast to the rock.

The rock which has been called diabase by previous writers appears to be of the same general mineralogical composition as the coarser gabbros, but it is so fine grained that pyroxene and feldspar individuals are rarely distinguishable in the hand-specimen. This fine-grained phase is, in most places, of a grey-green color with occasional small grey feldspar crystals and, here and there, stringers of yellow-green epidote which mark the progress of alteration.

In spite of the apparent freshness of the hand-specimens of some of the coarser-grained gabbros, no specimen of gabbro or diorite was found which under the microscope did not show great alteration. In

most sections examined the original minerals are recognizable only with difficulty, and in some cases the identification of the original rock as a gabbro was made solely on the basis of the mineralogical association of the secondary minerals.

The outstanding fact in the alteration of the gabbro-diorites is the formation of large amounts of zoisite, pistacite, actinolite, and talc. Of these zoisite is the most persistent, rarely being absent.

A typical medium-grained gabbro from Bisby Ridge appears to have been a holocrystalline hypautomorphic-granular rock with about 50% of pyroxene and 50% feldspar. The slide now shows about 50% zoisite including a little interstitial grey matter which probably represents unaltered remnants of feldspar. The augite has partly altered to green hornblende and actinolite. The hornblende forms rims around some of the augite crystals and the alteration proceeds inward from this rim along the cleavage lines.

A specimen of gabbro from Drouin Ridge is medium coarse grained, very light grey in color verging toward white, and tinged green here and there by aggregations of pyroxene crystals. The percentages of the original constituents could not be determined, nor the variety of pyroxene or feldspar other than that the latter was a plagioclase. In its altered condition the rock contains 40% zoisite, 50% sericite, and 10% amphibole which includes both green hornblende and actinolite. In addition to these there are small quantities of chlorite, calcite, and fibrous serpentine.

A third specimen from the power line east of Coleraine village, which originally contained 60% feldspar and 40% diopside or diallage, now contains only saussurite and actinolite. The former of these secondary products developed from the feldspar, the latter from the pyroxene. In this slide a number of euhedral feldspar crystals may be seen enclosed in larger pyroxene individuals, thus showing that the feldspar crystallized first.

In an altered augite diorite from Drouin Ridge the texture was originally somewhat ophitic, but this is now masked by the alteration. The proportion of the original constituents could not be made out, but plagioclase was probably in excess. Scraps of oligoclase, pyroxene, and titanite represent the primary minerals which have been largely replaced by chlorite, leucoxene, serpentine, actinolite, calcite, zoisite, white mica, and magnetite. Alteration is 95% complete.

A number of rocks when examined under the microscope were found to be composed exclusively of secondary minerals. In such cases the original mineralogical composition is problematical. For instance, a rock containing 30% zoisite, 40% actinolite, 30% white mica, and a few flakes of fuchsite is considered to be an altered gabbro. The high percentage of zoisite and mica point to the presence, originally, of feldspar, and an indistinct banding of the fibrous minerals suggests that they may replace a twinned feldspar.

A rock from near the foot of the slope at the south end of Belmina Ridge contains chlorite, green hornblende, epidote, zoisite, white mica, remnants of an unidentifiable feldspar, titanite, titaniferous magnetite, and calcite. The epidote, zoisite, and white mica are abundant and

replace feldspar. The titanium minerals are altering to leucoxene. Titaniferous magnetite in abundant small grains is associated with chlorite as an alteration product of a completely chloritized ferromagnesian mineral. The distribution and form of the replacing grains suggests olivine. The green hornblende can be seen altering to chlorite in many places, but no evidence is at hand to show whether the hornblende is primary or secondary after pyroxene. No traces of the latter mineral are now present if it ever was there. Thus it may be concluded the rock is the altered equivalent of either a pyroxene-feldspar or hornblende-feldspar rock of the gabbro group.

The average gabbro of Chalet Hill is now an actinolite-zoisite rock. The zoisite is brown in color with low grey birefringence, the brown color probably being due to the inclusion or admixture with the zoisite of clayey material developed from the feldspar or from secondary white mica.

AGE, STRUCTURE, AND RELATIONS.

The relation of the gabbro to the more basic phases is clearly shown on Lemay Hill. It will be seen that the major part of this hill is mapped as gabbro, but much of the mass assumes almost the character of a breccia. A few bodies of pyroxenite of considerable size and many smaller fragments of the same rock are surrounded by a matrix of fine-grained gabbro or diorite. In some cases the fragments may have been torn loose from previously erupted pyroxenite. In other cases partially cooled pyroxenite seems to have been fractured, and the resulting crevices filled by the gabbroic magma.

The gabbro itself was not all intruded at one time. Older coarse-grained phases have been shattered, and the fragments are now imbedded in a finer-grained younger type. The intrusion of the gabbro was probably a long drawn-out process, one flood of material following another and breaking up the rocks already partly solidified. That the interval between intrusions became longer and longer may, perhaps, be inferred from the fact that the successive intrusive bodies of gabbro are progressively finer grained. This indicates more rapid cooling due to the lower temperature of the surrounding rocks.

The fine-grained dioritic rocks pass almost imperceptibly into what has been mapped as breccia. This gradation and the accompanying difficulty of differentiating between the two rocks is especially marked where much epidote is present, thus indicating great alteration, or where fragments of the other members of the igneous series are sufficiently numerous to make the rock resemble breccia. It should be noted, however, that in areas mapped as gabbro, although angular fragments of coarse-grained gabbro and of pyroxenite do occur plentifully in places, yet no fragments of the sedimentary rocks have been found. In the breccia, on the other hand, fragments of slate and quartzite are numerous and widespread.

GRANITE.

NAME.

Under the name granite are mapped all those rocks of a granitic texture which in the past have been called granites. As a matter of fact, very little of the rock so mapped is true granite, but it ranges

from granite through quartz monzonite, monzonite, granodiorite, and quartz diorite. The different members of this series are differentiated, in this paper, on the basis of the relative proportions of orthoclase and plagioclase feldspar present, as follows:

	Orthoclase	Plagioclase	Quartz
Alkali granite	100%-95%	0%- 5%	+
Granite	95%-65%	5%- 35%	+
Quartz monzonite	65%-35%	35%- 65%	+
Monzonite	65%-35%	35%- 65%	—
Granodiorite	35%- 5%	65%- 95%	+
Quartz diorite and diorite	5%- 0%	95%-100%	+

In this area all the types with the exception of the monzonite are very rich in quartz.

DISTRIBUTION.

Areally the granitic rocks are the least important of the Thetford series, but they are geologically interesting as affording evidence concerning the acid differentiates of the magma, and they seem to have an economic importance in their effect on the development of rich chromite and chrysotile deposits.

Most of the outcrops are small and in the form of dikes or irregular bodies penetrating the basic rocks. The only large mass lies just to the north of Bisby Ridge. Small outcrops may be found near the outlet of Breeches Lake, near the north shore of East Lake, on Lemay Hill, at the east end of Drouin Ridge, between Belmina Ridge and Caribou Mountain, on Bisby Ridge, and elsewhere.

LITHOLOGY.

QUARTZ-RICH QUARTZ DIORITE.

Quartz-rich quartz diorite was found in a large dike crossing the little hill one mile north of Brousseau Hill, and also on Drouin Ridge.

Megascopically it is a coarse-grained grey to white rock, very rich in quartz. Under the microscope it is seen to be holocrystalline, hypautomorphic-granular, a texture common to all the granitic rocks. The probable original composition was about: plagioclase 62%, quartz 35%, ferro-magnesian 3%. Most of the feldspar was certainly oligoclase with a little oligoclase-albite, but it has been altered very extensively to white mica, and determination of all pieces is not possible. Whether any orthoclase at all is present could not be determined with certainty in all slides, but the probability is that there is none. In one place a small amount of what appears to be microperthite suggests orthoclase. Zonal structure is well shown in the plagioclase, and many of the quartz grains have deeply sutured boundaries. Apatite, zircon, and titanite in minute crystals occur in the quartz and feldspar. The only ferro-magnesian minerals present are biotite and a few flakes of primary muscovite. Alteration has proceeded to a considerable extent as shown by the presence of white mica, zoisite, pistacite, kaolin, limonite, leucoxene, and chlorite.

GRANODIORITE.

Granodiorite is the commonest type of granitic rock found in the district. It outcrops on the most westerly of the three knobs south of Caribou Mountain, in the flat north of Brousseau Hill, on the north shore of East Lake, and in one or two other places.

In appearance the granodiorite does not differ markedly from the quartz diorite or the quartz monzonite. It is a coarse-grained whitish-grey rock with much glistening quartz.

The percentages of the essential constituents vary somewhat in this rock but the following table illustrates the general range:

Quartz 30%, oligoclase-albite 47%, orthoclase 20%, ferro-magnesian 3%.

Quartz 15%, oligoclase 75%, orthoclase 10%, ferro-magnesian practically none.

Quartz 12%, oligoclase 55%, orthoclase 30%, ferro-magnesian 3%.

The degree of alteration varies, but in every case the process has at least begun. Chlorite, white mica, zoisite, actinolite, kaolin, iron oxides, and pistacite all are present.

One slide shows the quartz and feldspar greatly crushed. Clumps of the primary minerals are surrounded by comminuted rounded corroded fragments of quartz and feldspar which show resorption and sutured texture. Through the crushed zone runs a band of crystalline secondary quartz and oligoclase-albite. The secondary feldspar is in short, small twinned laths in sharp contrast to the larger crystals of primary feldspar. This suggests recrystallization under dynamic action with the help of solutions. Where the band of secondary minerals runs across a large primary quartz crystal, the secondary filling is feldspar, demonstrating that transportation was active even if it was effective through only short distances.

Small euhedral orthoclase crystals were seen lying embedded in large plagioclase individuals.

QUARTZ MONZONITE.

Quartz monzonite is found near the north end of Belmina Ridge and on the hill at the east end of Drouin Ridge.

In appearance it closely resembles the granitic rocks already described. Percentage compositions range from, oligoclase 38%, orthoclase 40%, quartz 20%, ferro-magnesian 2%, to oligoclase 25%, orthoclase 40%, quartz 35%, ferro-magnesian almost none. Accessories are apatite, rutile, and zircon. The secondary minerals present are actinolite in radiating rosettes, chlorite, white mica, and iron oxides.

One slide examined is remarkable in that it shows perfect hexagonal and other good automorphic sections of quartz lying in crystals of orthoclase. Quartz is not in excess throughout the rest of the slide, but it must have been in excess of eutectic proportions at the beginning of the crystallization period with the result that a few automorphic quartz crystals formed. Automorphic sections of plagioclase also are embedded in orthoclase.

MONZONITE.

True monzonite was found only in the dikes cutting the serpentinized pyroxenite north of Bisby Ridge.

The rock is almost pure feldspar in about the proportions orthoclase 60%, oligoclase 40%, with a small quantity of biotite and a very few grains of granophyric quartz. Penninite, leucoxene, white mica, and kaolin are the secondary minerals. The rock has undergone shearing as is shown by the twisting of the lamellae of plagioclase. The plagioclase shows zonal structure, and the central zones are more altered than the fresh, clear borders.

BIOTITE GRANITE.

Biotite granite outcrops on a single knob near the outlet of Breeches Lake. It is finer grained than the granitic rocks already described and is slightly darker brown in color owing to the presence of much biotite. It is holocrystalline but by no means equi-granular. This is partly to be accounted for, perhaps, by the crushing and recrystallization which it has undergone.

In composition it is about as follows: orthoclase 55%, quartz 35%, biotite and another completely altered ferro-magnesian mineral 8%, oligoclase 2%. The accessory minerals are zircon, topaz, and muscovite. Alteration is slight, only a little chlorite and white mica being in evidence.

AGE AND STRUCTURE.

Granite in dikes or larger irregular masses cuts all the other members of the Thetford series. Nowhere were the granite dikes observed to have a fine-grained border, and this suggests that they were intruded while the surrounding rocks were still hot. On the other hand, inclusions of the country rock and gradation in the composition of the granite near the border of the dike are entirely absent. The granite is of uniform composition to the very edge of the dike, and the contact is sharp. This would hardly be the case if the dike were intruded while the surrounding rocks were still fluid or even in a highly viscous condition. We may conclude, then, that the granite was intruded into the other members of the series after they had solidified but while they were still at a very high temperature.

The granite itself is cut, here and there, by narrow dikes of very fine-grained, dense grey-green rock. These younger dikes are in sharp contrast to the coarse-grained granites and evidently were intruded into cold rocks.

BRECCIA.

NAME.

Under the name breccia have been mapped a number of different rock types which differ markedly from one another in appearance but which, collectively, are regarded as forming the contact, border, and superficial phases of the Thetford series. Of these the important types may be distinguished as the brecciated, the amygdaloidal, the ellipsoidal, and the bomb types.

As has been pointed out already, brecciated masses of all the igneous types are found. Pyroxenite shattered older serpentine; gabbro magmas brecciated and recemented previously irrupted gabbro; and diabase dikes cut all the older rocks. All such brecciated masses are of relatively small volume, however, and have been mapped with the normal unbrecciated rock. In those areas mapped as breccia, on the other hand, the abnormal character of the rock is the outstanding feature.

The character of the contact rocks in any one particular locality depends on the conditions of intrusion, the nature of the immediately underlying and overlying sediments if the latter were present, the proximity with which the intrusive mass reached the surface at the time of intrusion, and the volume of magma intruded. These points will be developed during the following discussion of the most conspicuous modifications of the breccia.

The different types grade into one another in all directions, in some places gradually, in other places with more sharply defined boundaries. No attempt was made to map them separately or to do more than to record the locality where each type may be seen best.

DISTRIBUTION.

The contact rocks outcrop in an irregular band extending with but two breaks from the south end of Belmina Ridge to the hill east of Coleraine village. A second interrupted band runs from near the north end of Belmina Ridge across Oak Hill. The most typical area lies around, and to the north of, Brousseau Hill. Two small masses appear west of Disraeli Bay at the contact between the Farnham and the L'Islet formations.

LITHOLOGY.

BRECCIATED CONTACT-ROCK.

A large outcrop of typical brecciated rock is to be seen on the hill just southeast of Coleraine village. At this point the molten magma was intruded into a mass of red Bennett slates, and as a result the slate was much shattered and in places fused and baked. Fragments from a few inches to several feet across, and long contorted stringers and bands of the sediments lie embedded in a paste of igneous rock. Small fragments of the slate included in the mass appear to have been entirely recrystallized and have assumed a very hard, flinty character, resembling a piece of volcanic glass. Where the metamorphism is so intense, the red color of the slate is lost. The thin edges of larger fragments also are glassy, but less intensely baked or even unaltered material is present in the center. The long, twisted, contorted stringers of red flinty rock probably represent fused slates which were strung out by the movement of the magma while they were in a semi-viscous condition.

Dark Ordovician slates also are found in parts of the mass but on account of their color are much less conspicuous. The Bennett quartzite is represented in the breccia by blocks of varying size, but on account of its very refractory character it has undergone very little change.

On the same hill just southeast of Coleraine is another exposure of breccia in which may be found fragments of nearly every rock type in the neighborhood. Quartzite, red slate, grey slate, pyroxenite, gabbro, and granite are all present in pieces from a few inches across to blocks six feet long and two feet wide. Apparently the intruding magma tore off and carried with it masses of all rocks with which it came in contact and through which it passed. Another splendid example of brecciated sediments and igneous rocks is to be found on the most western of the three peaks which lie about one mile south of Caribou Mountain.

An interesting effect of the intrusion is illustrated on the northern face of Drouin Ridge where the magma carried with it an irregular block of Bennett quartzite more than 100 feet long. This mass was completely shattered into blocks a foot or more in length and was then pressed together and recemented without the introduction of any appreciable amount of igneous material.

The paste of the breccia is more or less ropy where it makes up a considerable part of the mass, but in most places the amount of paste is small. Megascopically it appears to be of distinctly igneous origin. Under the microscope it is seen to be so thoroughly altered that any attempt to decipher the original mineralogical character meets with but indifferent success. In general, however, it appears to be similar to the rock of the ellipsoidal type which will be described below. One slide examined suggested an ash rock as the nature of the matrix of the breccia, but although this would not be improbable, the evidence was insufficient to warrant placing any great stress on the idea.

It is the writer's belief that this truly brecciated phase represents the contact between the intrusive and the surrounding sediments. Fragments of the deeper-seated igneous rocks also are present, all lying embedded in a matrix of andesitic or dacitic habit. At one place on the hill east of Coleraine village small gobs of igneous rock have been intruded into shattered red slate. Toward the east along the outcrop the amount of slate decreases, and at a distance of 100 yards from the first locality only a few bits of slate are scattered through a mass of igneous rock. From much of the area where it was probably present at one time, the breccia has been removed by erosive agencies, and it now appears only where it has been infolded or around the borders of the outcrops of the overlying Farnham slates.

ELLIPSOIDAL FLOW ROCKS.

Structure— Ellipsoidal, pillow, or flow structure is best shown in the more northerly of the two outcrops of breccia lying to the west of Disraeli Bay. Similar pillow structure may be found in several places on, and to the north of, Bisby Ridge.

Where best developed, ellipsoids make up the entire mass of the rock. The individual pillows are from two to four feet in length and from one foot to 18 inches in width. The outline is rather irregular, but in many of them one side is flatter than the others. Where a number of pillows with this characteristic lie close together, the flat side occupies the same relative position in each. This phenomenon has been considered by Collins and other writers as marking the bottom of the igneous mass, and such an interpretation would quite agree with other facts observed in this area.

The outside of each pillow is a dense, hard fine-grained rock which forms a shell from one inch to three inches in thickness. This shell was caused by the more rapid cooling of the surface of the lava, and it surrounds a soft, porous central portion which invariably is cracked transversely, probably as a result of tensional cooling strains. Many of the fractures have been filled subsequently by calcite, quartz, or both.

Where the pillows make up the entire mass of the rock, their deformed outlines show that they flowed one over the other before they finally settled down with tight joints. They are not so plentiful everywhere, however, and in some places the pillows are separated by a matrix of fine-grained, tuff-like material. Many of the pillows burst under the cooling strains while the interior was still imperfectly congealed, and the remnants of the fractured shell lie scattered in a ropy matrix which was squeezed from the interior. This fracturing varies from the formation of a few cracks across a pillow to a very complete brecciation of the whole shell into pieces two or three inches in size.

Lithology,—Even in the hand-specimen it can be seen readily that the ellipsoidal lavas have undergone extensive alteration. They are very soft and much shattered and it is with difficulty that a good hand-specimen can be obtained. The weathered surfaces are grey green. Here and there, remnants of crystals as much as one centimeter in length may be seen, and these give the rock a coarsely granular appearance when they are at all numerous.

Under the microscope the porphyritic character of the original rock can be made out clearly, but the phenocrysts themselves and the fine-grained groundmass are so thoroughly altered that the original mineralogical composition can only be guessed at. One typical slide is made up of actinolite and chlorite 70%, grey interstitial material some of which is undoubtedly quartz 20%, carbonates 8%, pistacite 2%, and a few grains of magnetite. Much of the quartz shows sutured texture and appears as a border around the chlorite. Fragments of oligoclase show cleavage and twinning. Actinolite is the most plentiful constituent, and a slight parallelism of the needles gives an impression of flow texture. Pistacite is scattered in saccharoidal grains throughout the mass.

Another slide is made up of talc 60%, secondary green hornblende, probably replacing pyroxene, 20%, serpentine or chlorite or both 10%, carbonates 8%, pistacite 2%. No feldspar is present unless represented by a little undetermined grey interstitial material. These rocks are probably the altered equivalents of rocks of about the composition of an andesite.

Origin—Much has been written by various writers about the origin of ellipsoidal structure, and Wilson[1] gives a very concise summary of the different views. In the present instance the rocks showing ellipsoidal structure are believed to have been forced upward until they reached the surface or at least until they rested under a very light load of sediments. The presence of ellipsoids between L'Islet quartzite and

[1] Wilson, M. E.: Geol. Sur. Can., Memoir 39, pp. 50-54.

Farnham slate, where the igneous rocks just peep out from beneath their covering, suggests that the lavas may have been intruded under a light cover of unconsolidated shales. It should be noted that the thickness of the igneous rock at this point is inconsiderable, and it would seem that it might be possible to develop ellipsoidal structure in the thin outpushing edge of such a sheet. If the presence of water be necessary to explain the formation of pillows, it may be supposed that the intrusion into and beneath the Farnham slates took place at a time when they were still wet muds. Probably, however, over much of the area the ellipsoidal structure was developed under surface conditions, but whether subaerially or subaqueously it is not possible to say.

THE BOMB AND AMYGDALOIDAL TYPES OF BRECCIA.

In many places the ellipsoidal lavas just described grade within a short distance into an amygdaloidal rock with no trace of ellipsoidal structure. The amygdules are filled by carbonates and quartz. In some places the rock is soft, friable, and porous and approximates pumice in character.

Over considerable areas on Bisby Ridge, to the west of East Lake, and on Oak Hill the breccia is of a different type which for convenience in field work was described as the "bomb" type. The bombs vary in appearance but for the most part are small, rarely exceeding one foot in diameter, and are composed of a white-weathering porous rock. On the weathered surface the contents have been dissolved out from the pores, but in the center the vesicles are still full of carbonates and quartz. Where plentiful these "bombs" make up as much as 50% of the rock, but over considerable areas they are very rare. Much of the rock from which "bombs" are absent, or nearly so, has been called diabase in earlier reports.

The paste in which the bombs lie is green or brown in color, more or less ropy in appearance, and seems to have flowed around the nodules. The rock is now greatly altered and is composed almost entirely of secondary minerals, carbonates, epidote, chlorite, and talc being especially abundant. Characteristically this rock is dull brown in color, is soft and easily broken, and has small bombs, or fragments of them, scattered through it more or less plentifully everywhere. It is cut by many diabase dikes.

OAK HILL BRECCIA.

A very special phase of the breccia is to be found in the band crossing the west side of Oak Hill. Here many fragments of a very hard, dense, glassy green rock, together with some pumiceous fragments, lie in a pasty, ropy, porous fine-grained matrix which contains much epidote.

The matrix is a fine-grained mottled rock of a general pistachio-green color with a slight violet tinge. The presence of much epidote is indicated by green streaks throughout the mass. In general the texture is vesicular, the vesicles being full of epidote, calcite, quartz, and chlorite. Microscopic examination of several specimens of the matrix show that it is now made up almost entirely of the following

secondary minerals: pistacite, chlorite, calcite, actinolite, white mica, kaolin, quartz, hematite, and probably a little titanite. Originally the rock appears to have been composed of a plagioclase, probably all oligoclase and certainly so in part, and a ferro-magnesian mineral, probably augite. The feldspar altered to calcite and white mica, the ferro-magnesian mineral to chlorite, epidote, and actinolite. Secondary quartz is clearly made out. In several places the calcite, pistacite, and chlorite are in large masses which suggest an original porphyritic structure. Remnants of a few large augite crystals bear this out. The rock may be called an altered flow-breccia and probably was a porphyritic andesite or dacite.

Megascopically the glassy fragments found in this matrix are fine grained, pistachio green in color, and show numerous small sparkling quartz crystals and aggregations of epidote. The texture is porphyritic, here and there vesicular with glassy groundmass.

Microscopic examination shows that the rock in these glassy fragments is an altered porphyritic andesite or dacite made up of groundmass 75%, phenocrysts 25%. The phenocrysts are of two generations, 15% large and 10% small. The large phenocrysts were probably orthoclase, the smaller certainly plagioclase. The orthoclase is altered completely and very little of the plagioclase remains. The original composition of the rock is indeterminable owing to nearly complete alteration to pistacite, calcite, quartz, kaolin, chlorite, zoisite, and actinolite. Of the primary minerals only a few laths of oligoclase-andesine remain.

Circular and oval patches are present in the groundmass. Some at least of these were cavities which now are filled with epidote, quartz, or calcite. For the most part the filling is of small irregular quartz grains with sutured texture, larger grains in the center and smaller and smaller toward the periphery with a border of pistacite grains around all. Some of the patches have much more irregular outlines and appear to represent primary crystals which have been embayed, resorbed, and replaced by quartz and pistacite. The mineral most likely to suffer such resorption is orthoclase. Some laths of plagioclase have been replaced entirely by pistacite.

The groundmass is made up of small grains of epidote and zoisite lying in a mat of fine actinolite needles and a small quantity of an indeterminable mineral which may be quartz, feldspar, or both.

Possibly still another phase of the igneous complex on Oak Hill is represented by a thin band of purple to black slates. The original composition is indeterminable and no minerals definitely known to be primary remain. The fresh rock probably consisted of fine feldspar laths in a fine-grained groundmass, but it is now composed only of chlorite, pistacite, yellow iron oxide, magnetite, hematite, calcite, white mica, quartz, and titanite. Thin sections show an apparent flow texture where stringers of chlorite bend around augen of quartz. Chlorite, mica, and iron oxide appear in bands which suggest shearing, and aggregate polarization is very marked. These slates probably represent a fine-grained sheared phase of the andesite.

ORIGIN OF THE BRECCIA.

The general appearance of the breccia on Oak Hill as well as the texture and structure suggests an effusive origin. These characteristics, together with the presence of considerable bodies of ellipsoidal lavas within the limits of the map-area, make it seem certain that the Thetford series includes minor quantities of effusive rocks along with the predominating intrusives. This theory has not been advanced previously so far as the writer has been able to learn. It appears equally certain that these effusives are part of the Thetford series and are not representative of an earlier or later period of igneous activity. Their close association with the intrusives, the fact that they always appear in a definite stratigraphic relation to them as well as to the surrounding sediments, and the way in which pumiceous, ellipsoidal, vesicular, and bomb types grade into one another and into the dioritic and gabbroic phases of the intrusive members of the series, leave but little doubt that all are the product of the same general period of igneous activity. The coarsely crystalline rocks are the deepest seated; the ellipsoidal lavas reached, or nearly reached, the surface, probably through fissures; and pumiceous or vesicular rocks and fragments of glassy igneous rock represent surface extrusions which are probably, although not certainly, of true explosive volcanic origin.

THE METAMORPHIC ROCKS.

DISTRIBUTION.

Metamorphic rocks are found only along the western border of the igneous mass. The main outcrop is in the form of a narrow band running from Breeches Lake to, and along the west side of, Belmina Ridge. A second smaller outcrop which is probably part of the same band lies close to the north boundary of the area just west of Caribou Mountain.

The metamorphic rocks lie just at the boundary between the sediments and the intrusive igneous rocks and include metamorphosed members of both groups.

LITHOLOGY.

HORNBLENDE SCHIST.

The major portion of the band of metamorphic rocks is composed of hornblende schist or closely allied schist. A typical specimen collected near the road at the south end of Belmina Ridge appears in the hand-specimen as a rather dark-green finely-laminated rock which shows many good hornblende cleavages on fractured surfaces. Under the microscope it is seen to be composed of 98%-100% well-crystallized green hornblende with accessory zoisite, epidote, hematite, magnetite, titanite, and a few fragments of feldspar altering to sericite. The origin of this pure hornblende schist is not certainly known, but it is the belief of the writer that it has been formed by regional metamorphism of a primary hornblende rock which outcrops nearby.

HORNBLENDITE.

The hornblendite is a dark-green well-crystallized rock with little or no signs of schistosity or lamination. It is composed of 98% green hornblende and small amounts of interstitial orthoclase, hematite, titanite, white mica, chlorite, and pistacite. The hornblende is slightly chloritized, and the chlorite imparts a rather low interference color to the whole slide. The interstitial feldspar is noteworthy. It is unlikely that secondary feldspar would be found in a secondary amphibolite, nor does it seem likely that the pyroxene of a feldspar-pyroxene rock would have altered so completely to hornblende leaving the feldspar so comparativly fresh. If this is a primary hornblende rock, as it appears to be, it affords a likely source for the hornblende schist already described and the eclogites to be described below.

HORNBLENDE-EPIDOTE SCHIST.

Not all of the schists of the area are pure amphibolites, however. A specimen from the boundary zone between the hornblende schist and the neighboring quartzite is composed of green hornblende 75%, epidote, largely pistacite but with some zoisite, 20%, quartz 4%, calcite ½%, and minor amounts of magnetite, picotite, titanite, and chlorite. This schist borders the quartzite and is marked off from it by a rather sharp boundary. It could not have been developed from the normal quartzite itself, nor does it seem likely that it would develop from the average basic igneous rock of the immediate neighborhood. Possibly it represents the effects of metamorphism on a dolomitic phase of the neighboring quartzite. The decided schistosity of the rock and the linear arrangement of the ovoid grains of quartz and epidote, point to dynamic metamorphism as the cause.

Still another modification of the schist, found to the west of Chalet Hill, contains as much as 10% of albite along with epidote and green hornblende. The rock from which this was formed probably contained pyroxene and a calcic feldspar. The adjoining igneous mass is gabbro, and it is a fair inference that gabbro was the source of the schist.

In places the hornblende is considerably chloritized. One specimen in which the hornblende is much altered has the composition: epidote 5%, green hornblende and chlorite 65%, quartz 30%, and accessory magnetite and titanite. Probably the chlorite, epidote, titanite, and quartz are, at least in part, decomposition products of the hornblende. Shearing of the hornblende individuals shows that the schists themselves have been metamorphosed after their formation. The high percentage of quartz makes it impossible that this rock is the metamorphosed equivalent of any basic member of the Thetford series. It is possible that it is the equivalent of a sedimentary bed rich in quartz, which had been somewhat soaked in the igneous magma before dynamic action gave it the schistose form.

HORNBLENDE ECLOGITE.

Hornblende eclogite is a handsome rock which is found locally along the southern border of the pyroxenite area south of Belmina Ridge.

In the hand-specimen it appears as a coarsely crystalline steel-grey to black rock with numerous scattered crystals of red garnet. In many places the garnets are concentrated in bands, but scattered garnets appear throughout the mass. The garnets are all small, rarely exceeding two or three mm. in diameter. Schistose structure is not prominent.

Under the microscope the hornblende, which is green and well crystallized, is seen to vary in amount from 60% to 90%, and the garnet from 2% to 15%. Epidote varies from none to almost 8%, and small accessory amounts of pyroxene, magnetite, picotite, oligoclase-albite, titanite, and chlorite are present. In one slide examined there is as much as 30% of quartz.

The rock is coarsely crystalline with the garnets in automorphic crystals surrounded by hornblende. Around the individual garnets is a border of epidote grains probably to be regarded as a reaction rim. Similarly, pistacite in the cleavage cracks of the hornblende is a secondary product of the hornblende. However, most of the epidote of the rock resulted from the action of the same forces which produced the hornblende itself. Where present, the oligoclase-albite appears as interstitial material lying between the individual pieces of hornblende and in the cleavage cracks. The feldspar has a highly sutured texture and resembles quartz, but cleavage is plainly visible in many of the pieces.

Origin of the eclogite.—The eclogite is clearly metamorphic in origin, but the source is doubtful. No intrusive is evident which could have metamorphosed the gabbro of the serpentine series by contact action and produced this rock. If it is a case of the metamorphism of gabbro, the pyroxene has gone over to hornblende and the feldspar to epidote and quartz. More probably the eclogite is a metamorphosed phase of the hornblendite. The presence of these two rocks in the same vicinity and nowhere else in the region, so far as is known, tends to support the idea that they are thus intimately associated.

THE DIKE ROCKS

The dike rocks, which represent the last phase of igneous activity in the Coleraine region, are of several types. In most instances alteration of the rock has proceeded to a considerable extent. The important types are described below.

LITHOLOGY.

DIABASE.

Only one specimen of true diabase was collected and this was from a dike on Chalet Hill. The diabase distinctly cuts a granitic dike. The rock is dark grey to green in color and very fine grained. It is, however, softer than such rocks commonly are and on examination under the microscope is seen to be wholly altered to secondary minerals. The composition of the altered rock is: green hornblende, for the most part actinolite and probably secondary from pyroxene, 65%, zoisite mixed with clayey material, probably from feldspar, 20%, partly altered grey interstitial material, probably feldspar with a little secondary quartz, 15%. The original diabasic texture can be made out readily by the arrangement of the secondary constituents.

DIORITIC DIKE ROCK.

A number of dikes in different parts of the area have been classed as diorite. The texture is commonly sub-ophitic with traces of spherulitic texture here and there. They are all fine-grained grey to greenish-grey, dark-colored rocks.

The freshest specimen found had the following composition: micropegmatite and small granular quartz grains 73%, oligoclase in laths lying in a matrix of micropegmatite and quartz 25%, epidote and associated chlorite 1%, pyrrhotite and pyrite ½% to 1%. The original ferro-magnesian mineral which was in very minor amount has altered to chlorite and epidote.

A specimen of augite diorite from a dike on the Coleraine road one and one-quarter miles north of Disraeli has the composition: micropegmatite interstitial between laths of feldspar 35%, oligoclase-andesine in automorphic laths 25%, calcite 10%, chlorite 30%, and accessory pyrite altering to limonite and hematite. Slight sericitization of the feldspar produces a cloudiness, and most of the laths show resorption effects in their etched borders. Texture is sub-ophitic.

As an example of the extreme alteration of what appears to have been a sub-ophitic dioritic dike rock, the following composition may be noted: chlorite, calcite, sericite, and zoisite 83%, grey interstitial material, in part quartz, possibly secondary, and in part feldspar, 15%, pyrrhotite and titaniferous magnetite 2%. There are suggestions of sub-ophitic texture here and there.

A dike carrying appreciable quantities of arsenopyrite is composed of andesine 90%, chlorite 8%, quartz 2%, and accessory sericite, calcite, titaniferous magnetite, and arsenopyrite.

A pyrrhotite-rich spot in a diorite dike showed the following association: pyrrhotite with some pyrite and chalcopyrite 50%, pistacite and zoisite 30%, quartz 15%, chlorite 3%, feldspar and calcite 2%. The quartz is of two periods of crystallization. A mass of fine-grained quartz in sutured, inter-locking grains is cut by bands of coarser-grained quartz. Many of the pyrrhotite grains are surrounded by a band of epidote of varying width, and what feldspar is present appears in cracks in the pyrrhotite, none being found associated with the quartz. From these considerations it would appear that the pyrrhotite and feldspar are primary magmatic constituents of the rock. The epidote is secondary and was derived from a primary ferro-magnesian mineral now completely altered. The quartz is secondary, partially recrystallized, and probably was deposited by cold solutions.

GRANOPHYRE.

A fine-grained gray to black dike rock carrying pyrite and much feldspar in small grains cuts across the northwest slope of Lemay Hill. On weathered surfaces this rock resembles a weathered gabbro. The groundmass is granophyric over most of the slide but here and there is finely granular like a true quartz porphyry. Texture is spherulitic to slightly porphyritic. The phenocrysts when present are oligoclase-albite and quartz and make up from one to two per cent of the mass. The secondary minerals are quartz, epidote, calcite, chlorite, and sericite. The very small content of epidote and chlorite points to a low percentage of ferro-magnesian minerals in the original rock.

QUARTZ PORPHYRY.

Two masses of quartz porphyry were found, one at the foot of the east slope of Lemay Hill, the other on the small peaks one mile south of Caribou Mountain. The rock is light grey to greenish grey in color and holocrystalline. The abundance of quartz grains makes it resemble a very coarse-grained quartzite. Under the microscope the porphyritic texture is clearly evident with phenocrysts making up five per cent of the mass. The phenocrysts are of quartz, oligoclase, orthoclase, and biotite in sub-equal amounts. The groundmass is mainly a micropegmatitic intergrowth of quartz and feldspar. Here and there are a few radiating bundles of tiny needles, and in a very few places the groundmass has a miarolitic texture.

PEGMATITE.

Pegmatite, found in only a few small dikes, is a hypautomorphic-granular, holocrystalline rock, composed of oligoclase-andesine 80%, micropegmatitic quartz interstitial between feldspar 15%, calcite 3%, sulphides 2%, and a little chlorite.

APLITE.

Narrow dikes of gray to pink aplite are numerous. The material is very fine grained. No idea of the constituents can be obtained from the hand-specimens, but their nature can be made out easily under the microscope.

QUARTZ-FREE EPIDOSITE.

Two dikes, each a couple of feet wide, were found on Chalet Hill. On examination they were found to contain over 90% zoisite. The original character of these dikes is uncertain. In one slide 8% serpentine, a few flakes of white mica, a few remnants of feldspar, say 2%, and 90% zoisite make up the rock. The serpentine forms pseudomorphs after some ferro-magnesian mineral. The feldspar fragments and the few flakes of sericite lie in the midst of the zoisite. In the second dike the rock is 98% zoisite.

So far as the writer knows, no epidosite is described in the literature as being free from quartz. The suggestion is that the rock of these dikes was a pure feldspar pegmatite, and that it has been altered completely to zoisite. The quartz which must have been formed at the same time as the zoisite has been removed entirely. Quartz may be in association with this rock in the field and may have been overlooked since large masses of vein quartz are common in the surrounding country rock. The explanation given above of the origin of the epidosite is supported by the fact that dikes of almost pure feldspar only slightly or partly altered to zoisite, sericite, etc., are found here and there over the area. These dikes are devoid of all traces of any ferro-magnesian mineral, but in places they show some quartz and seem to represent the extreme siliceous end of the Thetford series. In most places the rock is so badly decomposed that it will crumble between the fingers into a mass of loose quartz grains and partly kaolinized and sericitized feldspar.

TRACHYTOID GRANITE-APLITE.

Trachytoid granite-aplite is a porphyritic rock with 10% phenocrysts and 90% groundmass. The phenocrysts are albite to oligoclase-albite. Ninety-five per cent of the groundmass is made up of quartz and a feldspar with index lower than the index of Canada balsam, possibly orthoclase or oligoclase-albite. Calcite, pistacite, and chlorite together make up the remaining five per cent.

In all the dike rocks in which the feldspar present was identified, it is noteworthy that it is never more basic than oligoclase-andesine. Absence of calcium-rich feldspar is pronounced in all the rocks of the district.

MODE OF ORIGIN OF THE IGNEOUS ROCKS.

The best section of the igneous rocks to be found is on Drouin Ridge, and it has been described by Dresser[1]. Within a distance of 1,500 feet north and south across the ridge all the important members of the igneous series are well exposed. Starting from the foot of the cliff and proceeding northward in direction and upward in the stratigraphic column, the rocks are met in the following order: serpentine, pyroxenite, coarse-grained gabbro, fine-grained gabbro, breccia, granite. The serpentine rests on quartzite dipping to the north at an angle of about 65°. The breccia is overlain by slates dipping in the same direction at about the same angle. Thus at this point, the igneous body is about 600 feet in thickness. The boundaries between the adjacent phases are nowhere sharp. One rock grades into the next without any break, but so suddenly that it is possible in most places to locate an approximate petrographic boundary within 20 or 25 feet.

A similar, though less sharply defined and less clearly exposed, arrangement of the different members of the Thetford series may be seen at a number of places between Drouin Ridge and Breeches Lake, and also on the ridge northwest of Brousseau Hill.

The various members making up the igneous sheet appear to have been formed from a common basic magma by a differentiation in place after intrusion. The differentiation may be theoretically explained by fractional crystallization and settling. Let us suppose that the olivine crystallized first and settled to the bottom of the molten mass forming dunite. Pyroxene then began to crystallize and, mixing with the last settling crystals of olivine, formed peridotites of progressively lower olivine content. When olivine failed entirely pyroxenite resulted. After feldspar began to appear gabbro was formed in large masses, becoming finer and finer grained toward the surface.

If the several rock types are the product of a number of distinct, successive eruptions and were injected one after the other, we would expect to find, in some places at least, sharp boundaries between the distinct sheets which would necessarily result from this mode of injection. No such boundaries were seen. On the other hand, there is much evidence to show that the whole body of igneous rock was not intruded at one

[1] Dresser, J. A.: Geol. Sur. Can., Memoir 22, p. 49.

time. Dunite was not seen to cut any of the other members of the igneous series, but pyroxenite dikes intrude the dunites on Oak Hill and elsewhere. Gabbro intrusions brecciated previously irrupted pyroxenite and gabbro, and dikes of granite and aplite cut all the other phases. On Lemay Hill and on the big hill east of Coleraine toward the power line, coarse-grained gabbro and pyroxenite has been shattered, and the fragments united into a sort of breccia, by a finer-grained gabbro. Numerous small dikes of a fine-grained hard dioritic or porphyritic rock cut all the other members of the igneous series.

The numerous dikes and the brecciation of some of the igneous rocks point to successive intrusions. Since the material of most of the dikes and of the matrix of the brecciated masses of gabbro and pyroxenite is commonly well crystallized, it is probable that the later intrusions took place during the same general period of igneous activity and while the mass of the main intrusion was still somewhat hot.

In the opinion of the writer the initial phase of the igneous action was the most extensive. A laccolithic sheet of very considerable size but of no great thickness, and of basic composition, was intruded into the sediments and differentiated in place. After the main intrusion had been completed the material remaining at the source of supply must have been of a more acid character since succeeding eruptions did not produce the most basic member of the series. While the main sheet was cooling and differentiating in place, the dregs of the magma presumably were undergoing a similar, if less complete, process. Subsequent irruptions produced the pyroxenite dikes and subordinate quantities of fine-grained gabbro which in many places burst through and brecciated the main sheet. The last extrusions from the basin, represented by granite and aplite, are of small volume and denote the close of the igneous period.

A subsequent recrudescence of igneous activity of very minor importance is represented by the various small dikes.

RELATIONS OF THE IGNEOUS ROCKS.

As exposed within this area, the relations of the different igneous types to one another are fairly definite, but as they grade into one another no sharp physical boundaries can be drawn between them. Where the base of the dunite is found, it lies upon a floor of L'Islet quartzite and grades upward into peridotite, pyroxenite, gabbro, and breccia, the latter in intrusive contact with slate. No exception to the above order of gradation was observed where two or more members of the series are found together, but all types are not present in all places where the igneous rocks appear. Thus, dunite is not present as the basal part of the igneous sheet on Belmina Ridge, and along the southeast boundary of the igneous outcrop west of Disraeli Bay the entire series is represented by ellipsoidal lavas and a few granitic dikes.

CHAPTER VI.

STRUCTURAL AND HISTORICAL GEOLOGY.

GENERAL STRUCTURE.

The area of the Coleraine map-sheet lies on the west flank of a broad geosyncline whose bounding anticlines are the Sutton and Megantic hills. The youngest consolidated rocks in this major basin are Devonian, and these, as well as all the older formations, are intensely folded. The deformation which is general throughout the whole basin is abundantly evident in the small section of it described in this report.

The strike of the more important structural features is northeast-southwest. In the neighborhood of Stenson at an elevation of 1,200 feet small infolds of Sillery slate indicate that the present surface approximates to the top of the L'Islet formation, and on the west side of Disraeli Bay the quartzites dip beneath the slate at elevations ranging from 1,000 to 1,200 feet. Midway between these points, however, the quartzite rises to an elevation of 1,500 feet with no evidence of any infolded slate. It is clear, therefore, that the broad band of quartzite between Disraeli Bay and Breeches Lake is an anticline, and it may be distinguished under the name Carineault anticline. It pitches to the northeast and disappears under the igneous rocks northeast of Coleraine. The younger slates in the valley of Pine River, north of East Lake, lie in a shallow synclinal basin which dies out toward the south and Breeches Lake. The Bennett quartzite along the western border and the Farnham slates in the southeast corner of the map dip to the southeast.

The igneous rocks form part of a folded and eroded laccolith which was injected above the L'Islet quartzite and below the Sillery slate. Along the flanks of Carineault anticline the igneous rocks outcrop in two bands which run across the central portion of the area mapped. Southeast of Bisby Ridge the intrusive dips beneath the Farnham slates and probably thins out rapidly if we may judge by the character of the outcrops west of Disraeli Bay.

No evidence has been found to indicate the probable extension of the igneous sheet westward beyond its present boundaries. The fact that the igneous masses lying along the contact between the intrusive and the quartzites are of much greater volume than are found elsewhere in the serpentine belt suggests that the westward extension may have been considerable.

In the eastern part of the Coleraine area the igneous rocks lie stratigraphically between the L'Islet quartzite and the Sillery and Farnham slates, but in the western part no trace of igneous rock appears around any of the small slate infolds near Stenson. It seems very improbable that the igneous mass did not at one time extend farther west than its present westward boundary, and the absence of igneous rock between the slate and the quartzite near Stenson may be explained on the supposition that in this area the laccolithic intrusion lay at a

different stratigraphic horizon. The most probable locus of the change would be along the line where the greatest masses of igneous rock are found, that is, along the line of Chalet Hill, Belmina Ridge, and Caribou Mountain.

If such a change of horizon really did exist, we can do no more than speculate as to whether the westward extension lay at a lower or a higher stratigraphic level than the top of the L'Islet. There do not seem to be any weighty reasons why large bodies of igneous material should accumulate at a point where the magma burst through soft, yielding overlying shales to a higher stratigraphic horizon. Nor do there seem to be any adequate sources of supply of igneous material to the eastward. In fact, the sheet appears to thin out rapidly in that direction.

On the other hand, if the sheet, which farther west was confined beneath the thick beds of resistant quartzite, broke through them and swept on eastward beneath the slates, we might expect a considerable body of igneous rock to be concentrated along the line where the magma escaped from pressure occasioned by the overlying unyielding beds. For these reasons it seems more likely that the igneous material, if ever present to the west of Belmina Ridge, lies underneath the quartzites rather than that it has been removed by erosion. This deduction is far from decisive.

GEOLOGIC HISTORY.

After the deposition of the Bennett formation and before the L'Islet formation was laid down, the rocks underwent intense folding. This is clearly shown by the much more intense deformation of the older quartzite. It is probable that a long period of erosion followed and that the pre-Cambrian surface went far on the way toward base level.

During Cambrian time a period of sedimentation followed in a gradually deepening sea, and the L'Islet and Sillery formations were deposited, presumably conformably one upon the other.

At the close of the Cambrian the land emerged, and a period of erosion began.

Following re-submergence, the Farnham slates were laid down. The unconformity between them and the Cambrian rocks is marked by the basal conglomeratic slates of the younger formation. Probably Silurian and Devonian rocks also were deposited in parts of this area, but within the map limits they have been entirely removed if ever present.

Emergence of the Ordovician or younger beds was followed by the intrusion of the Thetford series. Then came a gentle folding of all the rocks including the igneous.

So far as known, subaerial erosion went on from middle Paleozoic to Pleistocene times. In the Pleistocene glaciation was general, and the mantle of till and alluvium was laid down.

Post-Pleistocene erosion has added a few minor features to the topography and given it its present expression.

CHAPTER VII.

ECONOMIC GEOLOGY.

The only minerals of economic importance found within the area included in the Coleraine sheet are chromite and asbestos. Both have been mined at one time or another, but there is no production of asbestos at present. A small annual tonnage of chromite comes from a number of prospects on Caribou Mountain and Belmina Ridge.

ASBESTOS.

On several occasions within the past fifteen years attempts have been made to produce asbestos on a commercial scale from a number of deposits within the area mapped. Optimistic promoters installed mills before thoroughly testing their ground, and in each case the property was abandoned shortly, to the detriment not only of the investors but of the mining industry as a whole. A large mill, a railway, and a cable-way were built around the pits at the south end of Belmina Ridge. This plant operated for a few months, extracted a few thousand bags of asbestos, and then shut down. It is now falling into decay. Another mill was erected beside the serpentine outcrop one mile east of Breeches Lake. Apparently the sole reason for building a mill was the presence of the serpentine as no asbestos fibre is to be seen in the rock. This mill never turned a wheel and, after standing for a number of years, was sold for a few hundreds of dollars and transported to a new prospect on Bisby Ridge, half a mile east of the map limits. During the summer of 1916 a railway three miles long was built to this new prospect to connect it with the Quebec Central Railway at Coleraine Station. Unfortunately it gives little evidence of being more profitable than its unsuccessful predecessors.

On the whole, no evidence was seen which gives promise of important deposits of high-grade asbestos being found within the area included in the Coleraine sheet. The rich deposits of Thetford and Black Lake, a few miles to the north, are found in large bodies of peridotite and dunite, the most basic members of the igneous series. Within the map-area no large masses of these basic rocks are known. They are present, it is true, in a thin sheet at the base of the intrusion and here and there as small masses differentiated from the more acid pyroxenites. In such places minor amounts of good asbestos have been discovered. Nevertheless, the quantity of this high-grade material is so small and the quality of the short fibre found here and there throughout the more acid rocks is so poor, that competition with the fully established mines of Thetford and Black Lake is not possible.

The demand for asbestos is very brisk at the present time, the price of No. 1 Crude having been as high as $600 per ton in 1916. Further, the uses to which asbestos is being put are multiplying so rapidly that the demand will almost certainly keep abreast of, if it does not outdistance, the supply. Over 80% of the Canadian production goes to the United States.

All the asbestos of the region is of the chrysotile variety, essentially the same in chemical composition as the serpentine in which it is found. Both cross fibre and slip fibre are present, the cross fibre in the serpentinized dunites and olivine-rich peridotites, the slip fibre more commonly in the sheared serpentinized pyroxenites and acid peridotites. The cross fibre or vein type is crystalline in character, the crystals standing perpendicular to the walls of the fissures, and it is found only in olivine-rich rocks. The slip fibre is associated with zones of shearing, the development of fibre being correspondingly less where the movement was less.

The absence of any considerable deposit of asbestos and of operating quarries prevented a careful study of the origin of the fibre, but this will be undertaken in the immediate future in the neighboring Black Lake and Thetford pits where conditions for observation are excellent. A good and concise summary of previous views on the origin of asbestos is given by Dresser.[1]

CHROMITE.

Chromite occurs as disseminated grains and larger masses in the most basic phases of the intrusive, but only rarely is it present in minable quantities. Isolated grains or small gobs of chromite may be found nearly anywhere in the dunite and peridotite, rarely in the olivine-bearing pyroxenites, and scarcely ever in the purer pyroxenites. Here and there in the serpentinized dunite are masses of more considerable size. The chromite occurs in irregular bodies, more or less lens shaped, but without any definite walls. Commonly, a mass of chromite is surrounded by serpentine in which are disseminated chromite grains, the chromite content becoming less and less away from the nucleus. The individual gobs are not large, in most cases, but at the Bennett pit on the south side of Caribou Mountain a single stringer was traced for 100 feet.

From all the evidence seen the origin of the chromite is best explained by a process of differentiation in the cooling igneous magma, the chromite being the first mineral to crystallize. As with the asbestos, however, the limited chances for observation afforded but little opportunity for a careful study of the question. This also will be undertaken in 1917 in the Black Lake region.

Many small prospect pits have been opened up from time to time within the limits of the map-area, but in nearly all cases the amount of chromite present is so small that the rock can not be considered an ore. At present there is a small production from three or four little quarries on Caribou Mountain and on Belmina Ridge. The principal producer, and the only one in which machinery is used, is situated in the band of serpentine on the south slope of Caribou Mountain, just west of the Ireland-Coleraine township line. It is known as the Bennett pit and is operated by Mr. Bennett of Thetford. It produces a ton or so of fairly good, 35% to 40% ore every day. The output of the other prospects is negligible, being only a car or two per month.

[1] Dresser, J. A.: Geol. Sur. Can., Memoir 22, pp. 61-70.

At present war prices chromite which can not be profitably worked under normal conditions can be mined and sold at a profit. During the year 1916 a small concentrating plant was put in operation near Black Lake and is treating a considerable volume of low grade ore from the pits to the east and south of the village. Transportation to this plant from the pits around Coleraine would be expensive, however. The quantity of the ore in sight, as well as its quality, makes it improbable that the life of the few small pits in operation will survive the war-time demand and high prices which make hand cobbing of ore taken from small lenses a profitable occupation at present.

COPPER.

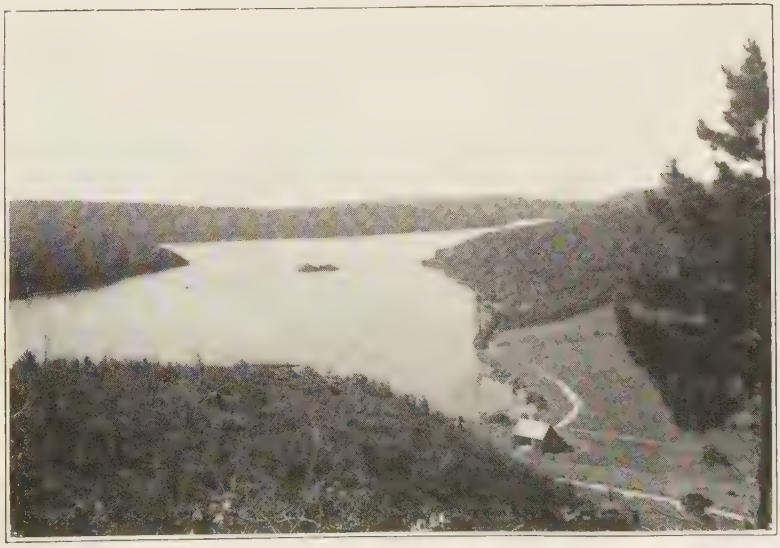
During 1915 a small pit and a couple of diamond drill holes were sunk in a diorite dike which cuts the breccia near the end of the side-road, one-quarter of a mile northwest of Brousseau Hill. No ore body was found. Small quantities of pyrrhotite, bornite, chalcopyrite, and arsenopyrite appeared at the surface in a silicified shatter zone in the dike and led the prospectors to hope that a considerable body of ore might be encountered. No such hopes are now entertained.

A similar small showing of chalcopyrite is to be found in a dike on Pine River in the midst of the gabbro area, northeast of Chalet Hill. A little trenching was done but nothing encouraging was encountered.

MOLYBDENITE.

A few flakes of molybdenite were seen in the granite and serpentine along the contact between these two rocks on the west slope of the small ridge northwest of Brousseau Hill.

West of Belmina postoffice, showing characteristics of an area underlain by Bennet and L'Islet quartzites.



Looking south over Breeches Lake from Chalet Hill.

Gabbro cut by dykes of gabbro on the west side of Chalet Hill.

Breccia on hill just southeast of Coleraine village.

Ellipsoidal flow rocks north of Bisby Ridge, showing "pillows" and the fragments of fractured "pillows."

Near view of several "pillows"

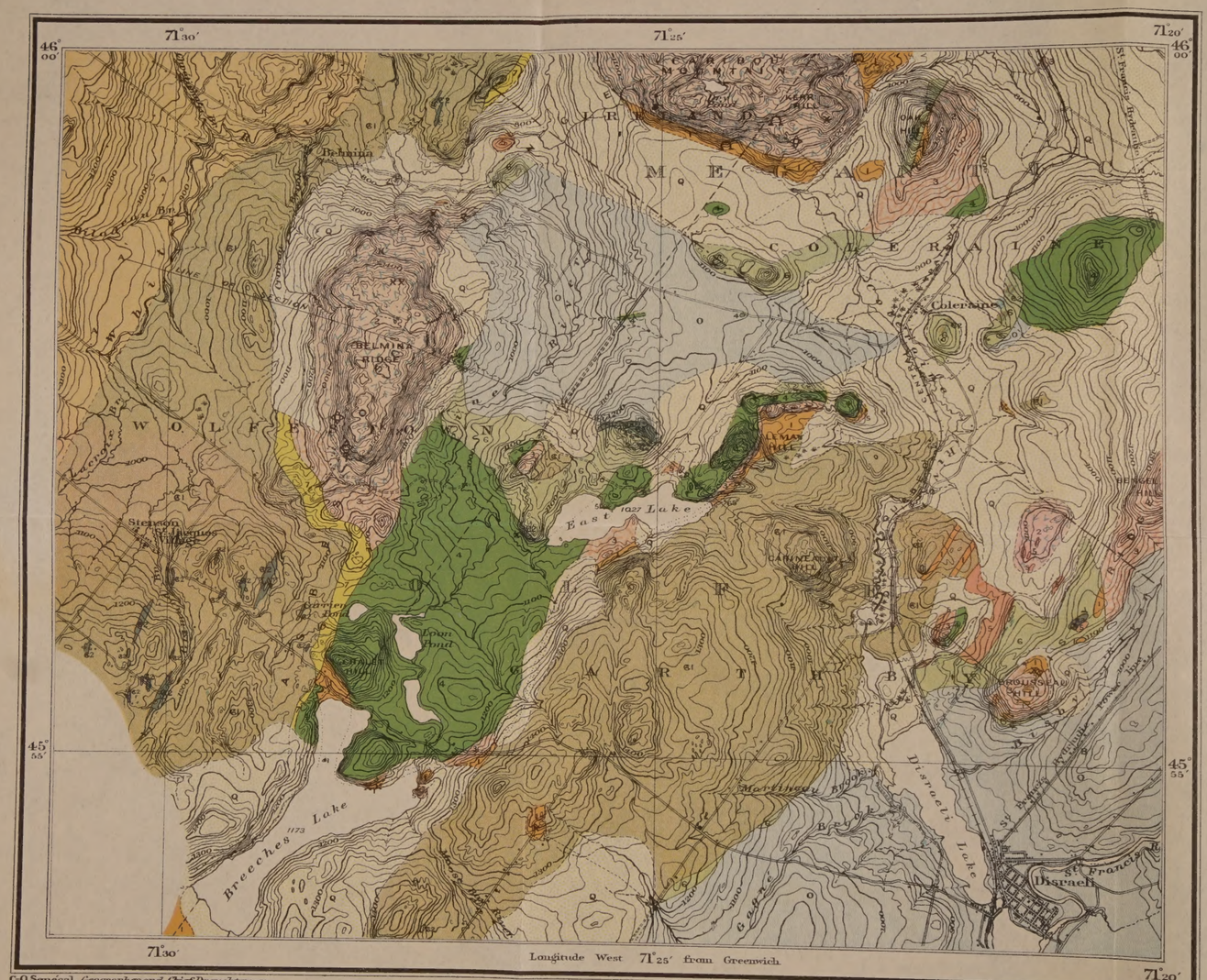
Canada
Department of Mines

HON. E. L. PATENAUDE, MINISTER; R. G. McCONNELL, DEPUTY MINISTER.

GEOLOGICAL SURVEY

Issued 1917

Structural Section along line A B
Horizontal and Vertical Scale 63,360



C. O. Senécal, *Geographer and Chief Draughtsman.*
A. Jomes, *Draughtsman.*

Catalogue No 1677

LEGEND

QUATERNARY

RECENT AND PLEISTOCENE

- Q — Alluvium and glacial deposits

POST-ORDOVICIAN

- 8 — Dikes
- 7 — Metamorphic hornblende schist
- 6 — Brecciated, amygdaloidal, ellipsoidal contact phase of the serpentine series
- 5 — Granite
- 4 — Gabbro, diorite
- 3 — Pyroxenite *(largely unaltered)*
- 2 — Serpentinised pyroxenite *(for the most part with small masses of serpentinised peridotite)*
- 1 — Serpentinised dunite and peridotite

PALÆOZOIC

ORDOVICIAN (?)

- O — Farnham(?) black pebbly slate, chert

CAMBRIAN (?)

- C2 — Sillery(?) red and purple slates, sandstone lenses
- C1 — L'Islet(?) quartzite

PRE-CAMBRIAN

- A — Bennett quartzite schist

Symbols

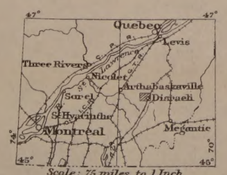
- Chromite
- Asbestos
- Prospects
- Geological boundary *(defined)*
- Geological boundary *(approximate)*
- Geological boundary *(assumed)*
- 65 / 1 — Dip and strike

LEGEND

- Streets and buildings
- Roads *(along township boundaries)*
- Roads *(good)*
- Roads *(poor)*
- Bush roads, paths
- Railways
- Mine tramways
- Power lines
- Bridges
- Churches
- Schools
- Post offices
- County boundaries
- Township boundaries
- Rivers and lakes
- Watercourse *(with intermittent flow)*
- Marshes
- 800 / 600 — Contours *(showing land forms and elevations above sea-level) Interval 20 feet.*
- 1000′ — Figures *(showing heights in feet above sea-level)*

Geographical position based on the latitude and longitude of triangulation station Thetford Mountain, established by the Geodetic Survey of Canada.

Approximate magnetic declination 17°30′ West



To accompany Summary Report by R. Harvie, 1916.

COLERAINE
MEGANTIC AND WOLFE COUNTIES
QUEBEC

Scale, 1 / 63,360

Miles 1 ¾ ½ ¼ 0 1 2 3

Kilometres 1 0 1 2 3 4 5

1 MILE TO 1 INCH

GEOLOGY

R. HARVIE, (IN CHARGE) 1915, 1916.
J. K. KNOX, 1915, 1916.

TOPOGRAPHY

D. A. NICHOLS, 1913, 1914.
S. C. McLEAN, (TRIANGULATION) 1913.